Learning with Hypermedia: The Impact of Content Design and Learner Characteristics on Navigation and the Knowledge Acquisition Process

Von der Carl-Friedrich-Gauß-Fakultät der
Technischen Universität Carolo-Wilhelmina zu Braunschweig

zur Erlangung des Grades
Doktor der Philosophie (Dr. phil.)

genehmigte
Dissertation

von **Mattias Steinke**
geboren am 26.07.1968
in Kirchheim / Teck

Eingereicht am:	24.08.2009
Mündliche Prüfung am:	10.05.2010
Referent:	Prof. Dr. Christian Floto
Korreferenten:	PD Dr. Thomas Huk
	Prof. Dr. Herbert Oberbeck

2010

Learning with hypermedia: students in action

Photo: Thomas Berger-v.d.Heide

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Acknowledgements

If you want happiness for an hour – take a nap.

If you want happiness for a day – go fishing.

If you want happiness for a lifetime – help someone else.

Chinese proverb

To write a dissertation would not be possible without the great help and continuous support of many people. So the next few lines shall be dedicated to all those who helped me finish this œuvre in different ways and whom I would like to thank most cordially.

This dissertation would not exist without the unfailing support of Prof. Dr. Floto of the Technical University (TU) Braunschweig. Testing his patience badly through the years he has continued to provide valuable scientific advice, encouragement, positive feedback as well as organizational support - a huge thank you for all of that!

I am immensely grateful also to PD Dr. Thomas Huk who has been an indispensable source of inspiration and help in every stage of the dissertation from the first brainstorming on how to set the focus to the discussion of results.

A big thank you to the other colleagues of the TU Braunschweig for keeping up the stimulating working atmosphere and scientific exchange in which good ideas could mature and be realized. Tobias Lipper who helped me to better understand the complex world of media science studies as well as Miriam Grupe and Steffen Lepa who gave manyfold support deserve special mention.

A cordial thanks also to Prof. Dr. Oberbeck of the TU Braunschweig for reviewing the dissertation in the final stage.

It was a pleasure to work at the L3S Research Center (formerly called the Learning Lab Lower Saxony) in Hannover with its infrastructurally more than state of the art facilities and access to an excellent international network. Many thanks to the colleagues there – I fondly remember the many fruitful discussions in the inviting cosy coffee corners – special thanks to Christoph Richter and Prof. Dr. Heidrun Allert who helped in their function as the L3S evaluation team to look at the research project from many different angles. The feedback especially while developing the questionnaires is much appreciated. Also thanks to Nils Jensen - it was a pleasure to share an open-plan office workplace with him.

I am also very grateful to the institute IWF Knowledge and Media in Goettingen for the possibility to make use of the CD “The Cell II – The Power Plant – Mitochondrium and Energy Metabolism” in the CRIMP research project and moreover for providing great technical and organizational support. As a former employee in the area of multimedia production I know the institute well and want to express my gratitude to many of the former colleagues for their help, especially Dr. Walter Stickan who helped to organize 25 iMacs for data collection and from whom I had learned a lot about multimedia production in the prior years. Christian Albrecht helped to create and visualize the different versions of the animations and Klaus Kemner was responsible for the CD’s speech and sound tracks. Last but not least sincere thanks to the team that developed the CD, especially Prof. Dr. Uwe Sander and Gertraude Kerlen who helped a lot with their advice during the production process of the different evaluation versions. Many thanks also to the company MMCD in Duesseldorf for the programming of the different CD versions and the integration of the logfile tracking function including an encoding tool.

The data collection in various “Bundeslaender” of Germany with 25 iMacs was not an easy task and would not have been possible without the immense flexibility and openess of many schools and universities. So time has come for a cordial thank you to the many teachers and students of different schools and universities who volunteered to work with the CD-Rom and who have shown a great interest in the project (see also list of participating schools and universities in the annex section).

Research ideas as well as results have to be presented and discussed. The weekly L3S info lunch provided a great opportunity to do exactly that. Moreover, the Center’s international links enabled the attendance of a number of conferences and workshops all over the world which allowed a good exchange with the international scientific community. Another very fruitful forum for discussion I always felt to be the interdisciplinary dissertation colloquium in Hannover and Berlin with Prof. Dr. Burkhard Priemer, Prof. Dr. Stefan Ludwigs, Dr. Christoph Stämmler, and a number of other attentive discutants who always had a friendly word to say after one’s presentation at the same time providing food for thought and work to do for many months: “...well done, but have you thought about..”. Very stimulating were also the EARLI special interest group meetings taking place every two years. I always went away with many good suggestions on how to improve my work. Special thanks to Prof. Dr. Peter Gerjets of the Knowledge Media Research Center KMRC and Dr. Katharina Scheiter of the Department of Applied Cognitive Psychology and Media in Tuebingen for their always helpful comments and the introduction of the newcomer to the cognitive load research community.

Last but not least the most cordial thank goes to my wonderful wife Susanne, source of encouragement and inspiration, coach, tireless critic, reviewer, editor and proof-reader. Without her support in all stages at all levels this dissertation would hardly ever have been finished. I dedicate this work to her and to our most adorable, lovely little daughter whose birth made us very happy and provided the final energy boost to finish this dissertation.

Summer 2009

Mattias Steinke

List of abbreviations

3D / 2D	3-dimensional / 2-dimensional
act	active learners
ANOVA	Analysis of variance
CBI	Computer based instruction
CBT	Computer based training
CFT	Cognitive flexibility theory
CLT	Cognitive load theory
CRIMP	Criteria for the Evaluation of Audiovisuals in Multimedia Productions
CTML	Cognitive theory of multimedia learning
ELM	Elaboration likelihood model
GEFT	Group-embedded figures test
GLM	Generalized linear model
glo	global learners
int	intuitive learners
ITPC	Integrated model of text and picture comprehension
L3S	L3S Research Center (formerly Learning Lab Lower Saxony)
LS	Learning style
LSI	Learning style index
M	Mean
N	Number of students
PCA	Principal component analysis
ref	reflective learners
SE	Standard error
sen	sensing learners
seq	sequential learners
st	start screen
SUCA	Fragebogen zur Sicherheit im Umgang mit Computern und Computeranwendungen (questionnaire on the individual's ease to use PCs and software)
tt	test tube
ver	verbal learners
vis	visual learners
VR	Virtual reality

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Executive summary

Educational software increasingly finds its way into classroom learning. The multi- and hypermedia environments offered distinguish themselves by the integration of increasingly sophisticated design features which in turn impact among others on production time and costs. The question arises whether the currently available software products seem well adapted to users' needs ensuring effectiveness and efficiency of learning.

While developing educational software the goal is to optimally support the process of learning and maximize the learning outcome. This is to be achieved by the proper design of the whole system as well as that of the content within the system. Furthermore, individual learner characteristics, e.g. prior domain knowledge, spatial ability and learning style, are to be taken into account as the latter play an important determining role regarding the way to learn with hypermedia systems.

Against this background research needs to investigate the way learner characteristics and content design properties are linked to navigation processes and knowledge acquisition strategies. A review of literature reveals that most studies conducted so far analyze the effects of single variables. Investigations on the learning process when using complex hypermedia environments and moreover the factors impacting on the software use are scarce still. Accordingly, there is a demand for further analyses aiming to shed light on the complex interplay of the different relevant parameters such as content design and learner characteristics. Moreover, ideally these studies are to draw on non-intrusive data sources such as log-files or observational data (see e.g. Bartholomé et al. 2006; Gerjets & Hesse 2004).

The presented doctoral thesis aims to bridge this gap: set in a realistic classroom scenario, the study captures a comprehensive image of the learning process with a complex learner-controlled hypermedia environment. The study investigates the impact of a number of content design features on software use, i.e. navigation as well as knowledge acquisition. Moreover, the complex interplay of individual learner characteristics such as prior domain knowledge, visual spatial ability and learning style with software use is analyzed. Offering various fresh insights into learning with hypermedia the study's findings contribute to the design of learning software that is well adapted to users' needs.

Four evaluation variants of a CD-ROM on cell biology offering different didactical and graphical designs but the same content were produced. Specifically, two modules of the CD were modified to investigate

a. the impact of 3D-models, close-up-views and static picture design: the module featured the organelles of the cell with the most complex version including freely movable models of animal and plant cells respectively as well as a cross section of the cell offering a three dimensional look and feel. In addition, oral explanations were provided. The other three versions presented the same content in a graphically gradually reduced manner: two differed in the existence / non-existence of close-up-views accompanying the narration. The simplest version consisted of a cross section of the cell designed in a two-dimensional look and feel. As outlined above, the oral explanations remained the same in all 4 variants on the CD-ROM.

b. the impact of animation design: this module presented an animation on the topic ATP synthase with the variants having been designed in a 2x2 factorial design. One factor represented the degree of reality (two-dimensional vs. three-dimensional) while the other factor dealt with the presence or absence of visual signals.

About 700 students of 15 schools and 3 universities in 5 different German "Bundeslaender" participated in the study. The knowledge acquisition and navigation behaviour of the examinees, i.e. students at high school and college level, was documented with encoded log-files and correlated with the individual's learner characteristics such as learning style, prior domain knowledge and visual spatial ability. Furthermore, the design features of the software variants were correlated with the software use. The data collection was carried out directly at schools as well as universities, each test series consisting of 3 consecutive sessions. To investigate potential differences of individual and group learning, part of the examinees were working individually with the software while others were working in dyads. Principle component analysis (PCA) was applied to get main usage factors that served as dependent variables in the subsequently calculated statistical tests.

The dissertation suggests various influences of learner characteristics and content design on the learning process. Specifically, it could be shown that

- not only the design of the whole hypermedia system but also that of single information nodes within such hypermedia systems indeed exhibit an impact on navigation and the use of learning support tools; this means that the content design exhibits a far reaching impact on the learners' processing strategies and use of the whole hypermedia environment;

- certain content design features such as complex 3D-visualizations impose a stronger impact than static pictorial or written elements;
- elements such as signals seem to have a more direct impact on cognitive processing whereas 3D-animations seem to stimulate – together with additional features of hypermedia - the knowledge acquisition process more indirectly;
- results from individual learning cannot be transferred easily to collaborative learning situations as social processes interfere with the impact of content design; however the study results indicate that some content design features such as 3D-models seem to have a strong impact on hypermedia use – strong enough to be stable even if students work in small groups;
- prior domain knowledge has a strong impact on all levels of hypermedia use;
- spatial ability shows a strong interaction with complex 3D-visualizations;
- learning style has mainly an impact on navigation and the use of learning support tools and much less impact on the content use than prior domain knowledge and spatial ability.

The study's results are discussed in light of an extended cognitive load theory for hypermedia learning environments. The latter claims that learner activities moderate cognitive load and thereby the users' success when learning with multimedia and hypermedia. The dissertation presented confirms and broadens this model especially regarding the impact of prior domain knowledge, spatial ability and learning style as well as the design of audiovisual content on learners' activities. Naturally, further fine-grained research in this field is needed to fully understand the process of learning with hypermedia systems and to improve the design of multimedia content that is well-adapted to users' needs. However, the thesis is hoped to present a building block to gain a clearer picture on what constitutes an effective and efficient hypermedia learning device thereby supporting the formulation of better guidelines for instructional multimedia and hypermedia development.

Zusammenfassung

Neue Medien kommen immer öfter auch im Klassenzimmer zum Einsatz. Die angebotenen multi- und hypermedialen Lernumgebungen zeichnen sich durch die Integration zunehmend ausgefeilter Designmerkmale aus, was sich wiederum in Produktionsaufwand und -kosten niederschlägt. Die Frage stellt sich daher, ob die derzeit erhältlichen neuen Medien den Bedürfnissen der Lernenden ausreichend Rechnung tragen und somit die Effektivität und Effizienz des Lernens mit hypermedialen Lernumgebungen gewährleisten.

Zielsetzung der Entwicklung von Lernsoftware sollte es sein, durch ein adequates Design des Systems sowie einer gelungenen Präsentation der Wissensinhalte innerhalb des Systems den Lernprozess optimal zu unterstützen und den Lernerfolg zu maximieren. Auch sollten die individuellen Eigenschaften der Lernenden einbezogen werden, da letzteren eine bedeutende determinierende Rolle bei der Art und Weise des Lernens mit hypermedialen Lernumgebungen zugeschrieben wird.

Vor diesem Hintergrund gilt es zu erforschen, auf welche Weise Eigenschaften der Lernenden und das Design der Softwareinhalte mit Navigation und Strategien des Wissenserwerbs zusammenhängen. In der Literatur werden größtenteils Studien beschrieben, die die Effekte einzelner Variablen untersuchen. Untersuchungen, die den Lernprozess bei der Nutzung komplexer hypermedialer Lernumgebungen und darüber hinaus die die Softwarenutzung beeinflussenden Faktoren beleuchten, sind bislang rar. Es besteht somit Bedarf an weiteren Studien, die auf das komplexe Zusammenspiel von verschiedenen relevanten Parametern wie Inhaltsdesign und Eigenschaften der Lernenden fokussieren. Auch sollten solche Analysen auf eine Vielzahl verschiedener, idealerweise nicht-intrusiver Datenquellen wie Logfiles oder Beobachtungsdaten (siehe z.B. Bartholomé et al. 2006; Gerjets & Hesse 2004) zurückgreifen.

Die vorliegende Doktorarbeit zielt darauf ab, diese Lücke zu schließen: Im Klassenraum durchgeführt und damit die realistische Lernsituation simulierend, zeichnet die Studie ein umfassendes Bild des Lernprozesses mit einer Nutzer-kontrollierten hypermedialen Lernumgebung. Der Einfluss einer Anzahl von Softwaredesignmerkmalen auf die Softwarenutzung, d.h. die Navigation und die Strategien des Wissenserwerbs, ist Gegenstand der Untersuchung. Daneben wird das komplexe Zusammenspiel zwischen individuellen Eigenschaften wie zum Beispiel fachlichem Vorwissen, räumlichem Vorstellungsvermögen und Lernstil und der Softwarenutzung untersucht. Mit ihren vielfältigen neuen Einblicken in den hypermedialen Lernprozess leistet die Studie einen wichtigen Beitrag zur Entwicklung von Lernsoftware, die den Bedürfnissen der Nutzer gerecht wird.

Vier Evaluationsvarianten einer CD - ROM zum Thema Zellbiologie verschiedenen didaktischen und graphischen Designs aber gleichen Inhalts wurden produziert. Insbesondere zwei Module der CD wurden modifiziert, um

a. den Einfluss von 3D-Modellen, Detaildarstellungen und dem Design statischer Bilder zu untersuchen: das Modul präsentiert die Organellen der Zelle: die komplexeste Version beinhaltet frei bewegliche Modelle von Tier- und Pflanzenzellen sowie einen dreidimensional gestalteten Querschnitt einer Zelle. Die Erklärungen werden in Sprechtexten gegeben. Die anderen drei Versionen präsentieren den gleichen Inhalt in einer graphisch graduell reduzierten Darstellung: zwei unterscheiden sich durch das Vorhandensein/ Nichtvorhandensein von Detaildarstellungen, die den Sprechtext begleiten. Die einfachste Version besteht aus einem zweidimensional gestalteten Querschnitt einer Zelle. Der Sprechtext bleibt in allen Varianten gleich.
b. den Einfluss des Designs von Animationen zu untersuchen: das Modul präsentiert eine Animation zum Thema ATP Synthase: die Varianten wurden in einem 2x2 faktoriellen Design erstellt: der eine Faktor variiert den Realitätsgrad (zwei- vs. dreidimensional), der andere das Vorhandensein/ Nichtvorhandensein visueller Zusatzinformationen (signals).

Etwa 700 Schüler/innen und Studenten/innen aus 15 Schulen und 3 Universitäten in 5 verschiedenen deutschen Bundesländern nahmen an der Studie teil. Navigation und Prozess des Wissenserwerbs der Teilnehmer wurde mit codierten Logfiles erfasst und mit individuellen Eigenschaften sowie den verschiedenen Designparametern der Software in Korrelation gebracht. Die Datenerhebung erfolgte direkt an den Schulen und Universitäten. Jede Testserie bestand aus 3 aufeinanderfolgenden Sitzungen. Um mögliche Unterschiede zwischen Einzel- und Gruppenlernen zu untersuchen, arbeitete ein Teil der Probanden einzeln, der andere in Zweiergruppen mit der Software. Mittels einer Faktorenanalyse (PCA) wurden Hauptnutzungsfaktoren ermittelt, die in den nachfolgend durchgeführten statistischen Tests als abhängige Variablen fungierten.

Die Ergebnisse der Dissertation zeigen verschiedene Einflüsse der Nutzereigenschaften und des inhaltlichen Designs auf den Lernprozess. Insbesondere konnte gezeigt werden, dass

- nicht nur das Design des gesamten Hypermedia-Systems sondern auch die Gestaltung einzelner Informationsknoten innerhalb des Systems bereits einen Einfluss auf die Navigation und die Nutzung von Lernwerkzeugen aufweisen; das bedeutet, dass die

Inhaltsgestaltung einen weitgehenden Einfluss auf die Lernprozesse und die Nutzung der gesamten Hypermedia-Lernsoftware hat;

- bestimmte Parameter der inhaltlichen Gestaltung wie komplexe 3D-Visualisierungen einen stärkeren Einfluss aufweisen als statische Bild- bzw. Textelemente;
- visuelle Zusatzelemente (signals) einen direkteren Einfluss auf kognitive Prozesse haben, wohingegen 3D-Animationen den Wissenserwerb eher – im Zusammenspiel mit zusätzlichen hypermedialen Elementen –indirekt zu stimulieren scheinen;
- Forschungsergebnisse zum Thema individuelles Lernen nicht ohne weiteres auf das Lernen in Gruppen übertragen werden können, da soziale Prozesse den Einfluss inhaltlicher Gestaltung relativieren; doch weist die Studie darauf hin, dass einige inhaltliche Gestaltungsmerkmale wie zum Beispiel 3D-Modelle einen starken Einfluss auf die Hypermedia-Nutzung aufweisen – stark genug um auch stabil zu bleiben, wenn die Schüler in Zweiergruppen arbeiten;
- das fachliche Vorwissen die Hypermedia-Nutzung auf allen Ebenen stark beeinflusst;
- das räumliche Vorstellungsvermögen eine starke Interaktion mit komplexen 3D-Visualisierungen aufweist;
- der Lernstil vorrangig einen Einfluss auf die Navigation und Nutzung von Lernhilfen und in sehr viel geringerem Umfang als fachliches Vorwissen und räumliches Vorstellungsvermögen auf den Umgang mit dem Inhalt hat.

Die Ergebnisse der Untersuchung werden im Zusammenhang einer erweiterten kognitiven Beanspruchungstheorie („Cognitive Load Theory“) für hypermediale Systeme diskutiert. Letztere postuliert, dass Nutzeraktivitäten in multimedialen und hypermedialen Umgebungen einen moderierenden Einfluss auf die kognitive Beanspruchung, den „Cognitive Load“, und somit den Lernerfolg haben. Die vorliegende Dissertation bestätigt und erweitert dieses Modell insbesondere hinsichlich des Einflusses fachlichen Vorwissens, räumlichen Vorstellungsvermögens und Lernstils sowie des Designs audiovisuellen Inhalts auf die Aktivitäten der Lernenden. Natürlich erscheinen weitere Untersuchungen empfehlenswert, um den Lernprozess mit Hypermedia-Systemen vollständig zu verstehen und die Gestaltung des multimedialen Inhalts genauer an die Nutzerbedürfnisse anpassen zu können. Die vorliegende Promotion ermöglicht, ein klareres Bild bezüglich einer effektiven und effizienten hypermedialen Lernumgebung zu gewinnen und dadurch die Formulierung besserer Richtlinien zur Entwicklung multimedialer und hypermedialer Lernsysteme zu unterstützen.

1 Introduction

The study presented provides a building block to design instructional software well adapted to the users' needs. It does so by shedding light on the complex interplay and influence that different design features of instructional multimedia environments exhibit on the learning process while taking individual differences into account also.

Throughout the world PCs and the Internet have become part of childhood and adolescence. This trend as well as the availability of increasingly sophisticated software have prompted schools, colleges and universities to open up to the integration of multimedia products in their instructional curricula, adapting the view that well-designed instructional software may represent valuable devices to help explain complex subjects (Liu et al. 2002). In the literature referred to as Computer Based Training (CBT), Computer Based Instruction (CBI), e-learning, multimedia, hypertext or hypermedia play an increasingly important role in learning and web-based instruction (e.g. Rikers et al. 2008; Kahiigi et al. 2008; Rowe & Asbell-Clarke 2008; Levinson et al. 2007; Sun & Cheng 2007; Schnotz & Lowe 2003; Beasley & Waugh 1996; Vollstädt, p. 50 2003). The new technologies are believed to be especially well suited to explain phenomena in natural sciences and engineering. These include biology (e.g. Seufert et al. 2009; Shelmet et al. 2008; Lu et al. 2007; O'Day 2006; Brünken et al. 2005; Zahn et al. 2004; Evans et al. 2004; Stiller 2003; Sonnenwald & Li 2003; Shih & Gamon 1999; Shapiro 2005; Anjaneyulu et al. 1998; Lee & Lehman 1993), medicine and public health (e.g. Brenton et al. 2007; John 2007; Ridgway et al. 2007; Hsieh et al. 2006; Noser et al. 2004; Floto & Huk 2002), chemistry (e.g. Ngu et al. 2009; Barak 2007; Wu & Shah 2004; Gauss & Urbas 2003; Graeber 2002; Wu et al. 2001; Hays 1996), physics (e.g. Ploetzner et al. 2009; Hron et al. 2007; Kim et al. 2007; Saab et al. 2007; Burke et al. 1998), geography and geology (e.g. Fiorina et al. 2007; Andris 1996), engineering and energy consumption (e.g. Ferens et al. 2007; Lux & Davidson 2003; de Jong & van der Hulst 2002; Zhu 1999).

Against this background an increasing number of instructional hypermedia materials find their way into classrooms: professional software companies offer products on a broad range of topics. Moreover, also teachers and lecturers work as multimedia producers: they make use of the possibility to search huge data bases to integrate multimedia content modules into their instruction curricula. Furthermore, different software tools enable pedagoges to create their own learning applications such as images, texts, videos, audios, 2D- or 3D-elements, see e.g. Deuff et al. (2004). In the area of molecular biology projects such as „lifelab“ try to bring authentic scientific experience to schools by means of multimedia and web technologies

(Schmitt et al. 2003). In universities and scientific institutions large quantities of valuable images and audio-visual media, for example in the field of life sciences, are produced already (Sander et al. 2003).

Creating multimedia material however poses - apart from the financial implications that need to be considered, especially when designing expensive simulations, animations and 3D-visualisations – a number of challenges concerning the structure of multimedia systems, the instruction goal to point the user to, the quantity of information to present, the navigation tools to offer and last but not least the design of the content modules and in this context the desired interactivity of the system (see e.g. Scheiter & Gerjets 2007; Graff 2003; Nielsen 2000; Evans & Edwards 1999; Verheij et al. 1996).

Against this background the question arises whether the currently available software programmes represent effective learning tools supporting optimal learning outcome in a classroom setting. A number of authors postulate that research on the users' needs as well as the implications for the learning process, i.e. the usage of the software, need to be strengthened: Fitzgerald and Semrau (1998) for example state that research on the interplay of learner characteristics, hypermedia formats, patterns of use, and learning outcomes is in its infancy. Chen & Macredie (2002) as well as Brusilovsky (2003) claim that more empirical studies are needed to help designers to develop learning environments that will take the advantages of hypermedia features into account at the same time focusing on learners' needs and individual differences. The results of such research are hoped to support a better understanding of the ways in which learners use hypermedia systems and the relationship between learner characteristics, software design, usage process, and learning outcomes. This information in turn is considered crucial for the design, the selection and use of effective instructional hypermedia systems (see also Opfermann 2008; Hays 1996).

In multimedia as well as hypertext research a number of studies have focused on the impact of content design on learning outcome in a restrictive experimental setting (see also Huk et al. in press; Reed et al. 1997). A review of the literature suggests that so far comprehensive research on the impact of audiovisual content design on learner activities, i.e. the software usage during the knowledge acquisition process, while working with complex learner-controlled hypermedia learning environments is missing.

The study presented therefore aims to make a contribution to bridge this gap: the doctoral thesis focusses on the impact of content module design on learner activities and processing strategies using a complex learner-controlled hypermedia environment. Moreover, the influence of individual learner characteristics on the learning process is investigated. The findings of the study are hoped to contribute to the design of learning software that is well adapted to the users' needs.

In accordance with the goals stated above the thesis is structured in the following way:

The *introductory chapter* consists of 5 parts:

1) the conceptual background, i.e. the models and theories developed for multimedia learning, that form the backbone of the study;
2) the user, his or her individual characteristics and the implications these have for using multimedial learning software;
3) the software, the implications of different design features and their usage;
4) the user-software interplay;
5) the project framework including the specific research questions this dissertation aims to answer.

The *methods chapter* subsequently describes in detail the project including the recruitment of examinees, the questionnaires developed, the hardware and last but not least the software and its variants used as well as the methods of analysis.

The *result and discussion chapters* describe the findings and their interpretation.

The *conclusions and outlook chapter* summarizes the lessons to be drawn and provides an outlook on possible additional experiments and analyses to be conducted to strengthen reasearch in this field further.

1.1 The conceptual background of learning with multi- and hypermedia

1.1.1 Definition of hypertext, hypermedia and multimedia

A study on learning with hypermedia and multimedia might usefully start out by clarifying some of the technical terms that are frequently used throughout the thesis as well as refered to in the literature.

There does not seem to exist one comprehensive, widely accepted definition of terms - what is called hypermedia by one author is frequently called hypertext by another (Unz 2000; Barab et al. 1996). Approaches to definitions are however available: Unz (2000) believes that hypertext stresses the structural aspect, namely the non-linear presentation of information nodes or units and links in an interconnected network (see also Boechler et al. 2002; Stanton and Baber 1994). She furthermore postulates that the term reflects the historical development starting out from text-based systems. The term hypermedia on the other hand focuses on the multimedial elements such as sounds, illustrations, videos etc. that can be integrated in the network. Multimedia-systems digitally combine various media such as text, sound, picture, movie with one another but do not necessarily need to be structured in nodes and links (Unz 2000). Hypertext and multimedia are therefore considered as two independent entities with hypermedia presenting an intersection.

In accordance to these definitions the software used in this study is considered a hypermedia product.

The conceptual framework in which the study and its research questions are embedded is illustrated by providing the following overview on the theories and models developed for learning with hypermedia.

1.1.2 Theories and models on learning with hypermedia

Various theories and models have been developed to describe learning with new media and the interdependencies between learners, goals and software. According to Kuhlen (1991) learners have to deal on three levels with the hypermedia learning environment: 1) on the content level with the information, 2) on the structural level with navigation, and 3) on the system level with the system functions (hard- and software). Thus, learning with multimedia and hypermedia challenges the users in respect to orientation, information search and navigation as well as processing of multiple forms of presentations and modalities (Plass 2005). To manage the latter the learners need different ways of sustainment to enable them to learn effectively (e.g. Lawless & Kulikowich 1996; Schroeder & Grabowski 1995).

Some theories have been developed to account for the integrated presentation of visual and verbal material in multimedia learning (Schnotz & Bannert 2003; Mayer 2001). Mayer’s cognitive theory of multimedia learning (CTML) is based on three central assumptions, namely a) the dual channel, b) the active processing and c) the limited capacity assumption.
a) the dual channel assumption states that two separate channels are used to process information. A first channel processes sounds in the working memory, resulting in verbal

models. A second channel is used to process images, resulting in pictorial models (see also Paivio 1991).
b) the second CTML-assumption focuses on the processing of all sensory input: the active processing assumption. This implies that the learner is actively engaged in processing information and makes an effort to construct coherent mental models. Typical cognitive processes involved in the latter are selecting, organizing and integrating.
c) the third assumption of Mayer's CTML is the limited capacity assumption. This implies that learners are limited in the amount of information they can process simultaneously along each channel (see also de Westelinck et al. 2005).
The active processing assumption is central to most cognitive theories. Lawless and Brown (1997) for example view learning as an active, constructive process in which knowledge acquisition is defined as the interpretation process of new information and its subsequent assimilation and accomodation into memory structures or schemata (see also Saxena et al. 2002; Goodyear et al. 1991). Schnotz and Bannert (2003) also present an integrated view and consider learning from verbal and pictorial representations as a task-oriented process of constructing multiple mental representations which affords information selection, organisation and model construction (see also Calvi 1997). Backed by multiple studies Ashby et al. (2002) moreover stresses that moderate fluctuations in feelings can systematically affect cognitive processing (for reviews see e.g. Ashby et al. 1999). Literature indeed suggests that positive affect increases a person's ability to organize ideas in multiple ways and to access alternative cognitive perspectives. In this context the cognitive flexibility theory (CFT) of Jacobson and Spiro (1995) has received a great deal of attention (De Jong & van der Hulst 2002). The latter postulates that approaching a domain from different angles enables learners to make multiple comparisons and relations and this leads to a "flexible" cognitive structure and better knowledge transfer.
The third assumption of the cognitive theory of multimedia learning, namely the limited capacity assumption, relates closely to the cognitive load theory (CLT) of Sweller and colleagues (see e.g. Ayres & Paas 2009; Sweller 2005; Paas et al. 2004; Krapp & Weidenmann 2001 p. 429 as well as the special issues devoted to its theoretical and empirical development, see e.g. Educational Psychology Review 2009; Instructional Science 2004; Educational Psychologist 2003; Learning and Instruction 2002). The CLT theory focuses mainly on learning of complex cognitive tasks in which learners are often overwhelmed by information elements and their interactions (Paas et al. 2004). The model can therefore be used to describe cognitive processes in multimedia learning and has many implications for the

design and evaluation of the respective material (Paas et al. 2004, Bruenken et al. 2003). CLT distinguishes between three types of cognitive load: intrinsic, extraneaous, and germane load. The intrinsic load is determined by the number and interactivity of the different information elements. The additional extraneaous or germane load is defined by the way in which information is presented to the learner. When it comes to cognitive processing of the to-be-learned material, e.g. by schema construction or automation, the additional load is called extraneaous or ineffective when it does not sustain these processes. It is called germane load when it contributes to foster them. All three types of load sum up to a total load that cannot exeed the memory resources available (see also DeLeeuw & Mayer 2008; Paas et al. 2004). Cognitive load theory has many implications for the design of learning materials which must, if they are to be effective, keep the extraneous cognitive load as low as possible during the learning process. In order not to influence learning performance negatively the instructive material needs to be well-adapted to the users' needs avoiding particulary low load (underload) or particulary high load (overload). Bearing this in mind designers of multimedia learning software need to strike the right balance between the goal to involve students in the learning tasks by using discovery-based hypermedia systems and the possible danger of overload when offering complex environments to learners. Brünken et al. (2005) claim that within the vast area of media-sustained learning the two well-established research directions on learning with hypertext and learning with multimedia coexist with little interaction. To the same end Plass (2005) highlights the necessity of the creation of a future framework to integrate these research directions under one roof. One theory providing the ground for an integrative approach might be seen in the cognitive load theory (CLT).

In CLT it is usually assumed that a specific instructional design elicits or induces a specific type of learner activity. No variability of learner activities as a reaction towards a specific instructional design is expected. In learner-controlled hypermedia environments however users' activities are influenced by the complex interaction of different factors, such as individual differences/ learner characteristics, system and content design features and type of task/goal. To describe complex usage processes in the light of the cognitive load theory (CLT) Gerjets and Hesse (2004) propose an extension of the CLT model that focuses on learner activities in hypermedia learning environments (for details see figure 1).

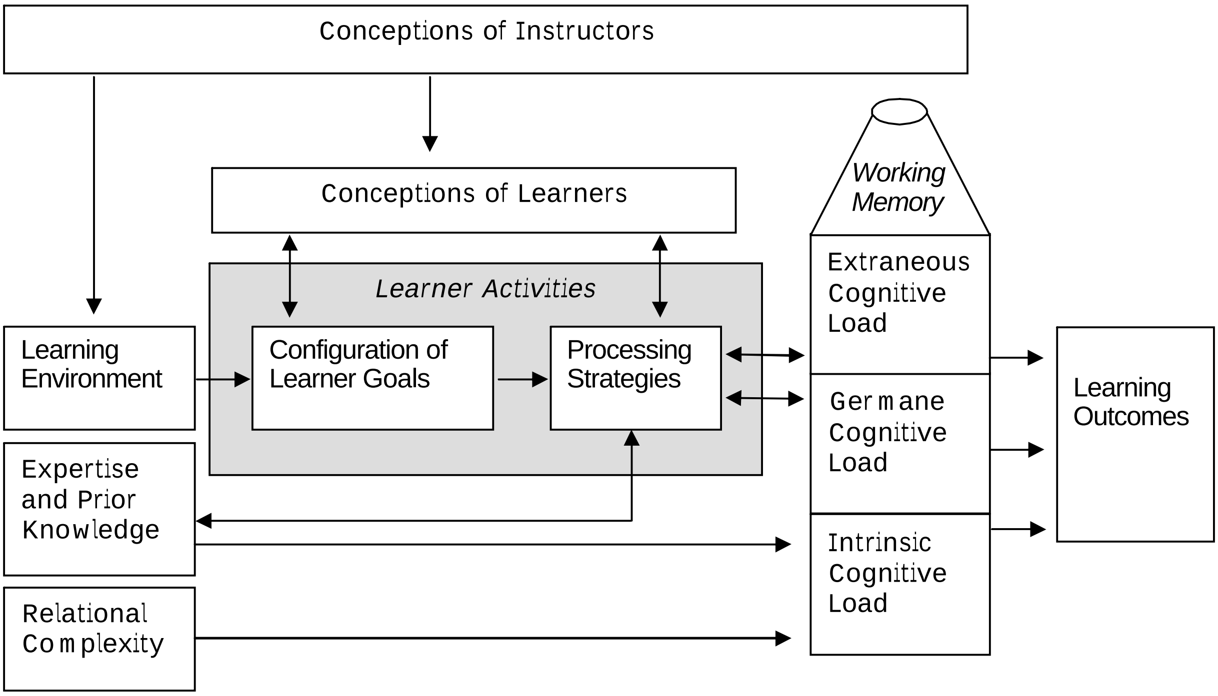

Figure 1 Learner activities, cognitive load, and learning outcomes (Gerjets & Hesse 2004)

The proposed model describes learner activities in terms of goals and processing strategies as moderators between the variables instructional design and cognitive load. The authors postulate that the appropriate type of learner activities depends on the instructional design as well as the learner characteristics and claim that the interplay between the latter is especially little deterministic in instructional settings that are characterized by a high level of learner control, e.g. hypermedia learning environments. Moreover, in their model the learner activities are the most important unit of analysis. Gerjets and Hesse therefore propose a fine-grained analysis of learning environments and learner activities to define which specific design features of learning environments and instructional tasks enable or elicit profitable learner activities.

The model assumes that the processing strategies mainly depend on prior knowledge and expertise. However, the latter are also influenced by learners' conceptions including a broad variety of beliefs, attitudes or study preferences. Opfermann (2008) investigated the impact of attitudes and epistemological beliefs on hypermedia learning and could show that these learner characteristics may influence how learners deal with learning contents, how much time and effort they put into learning and finally, how they perform. Other learner characteristics like cognitive and learning styles should be taken into account as the latter may represent strong predictive variables influencing processing strategies in hypermedia environments.

Against the conceptual background provided the study presented aims to contribute to a further augmentation of the extended CLT model as proposed by Gerjets and Hesse (2004) as well as to bridge the gap between existing multimedia and hypertext/-media research.

1.2 The user

1.2.1 Learner characteristics

A wealth of studies shows that learners can be differenciated with respect to various learner variables. These individual differences can have significant effects on student learning and patterns of interaction with hypermedia programmes (e.g. Plass 2005, Chen & Paul 2003; Chen & Macredie 2002; Unz 2000; Riding & Rayner 1998). Therefore, producing multimedia material for instruction, teachers and lecturers should keep individual learners' needs and differences in mind. Research very often focuses on cognitive and learning styles, computer literacy, prior domain knowledge, spatial ability (e.g. Hilbert & Renkl 2008; Brandt & Davies 2006; Cegarra & Hoc 2006; Cook 2006; Calcaterra et al. 2005; Mitchell et al. 2005; Lawless et al. 2002; Ford & Chen 2000; Reed et al. 2000; Shih and Gamon 1999; Lawless & Kulikowich 1998; Chen & Ford 1998; Reed & Oughton 1997), epistemological beliefs (e.g. Opfermann 2008; Bromme & Stahl 2003), as well as gender or cultural influence (Beasley & Waugh 1997; Beasley & Vila 1992). However, many findings on the role of individual differences in hypermedia learning remain controversial and so far not conclusive enough to derive general design guidelines (Gauss & Urbas 2003).

1.2.1.1 Prior domain knowledge

Domain knowledge can be defined as subject-specific knowledge. Obviously, in order to evaluate learning success with instructional software it is important to first of all assess this knowledge. Moreover, a multitude of studies suggests that prior domain knowledge exhibits a strong influence on navigation (e.g. Möller & Müller-Kalthoff 2000).

In a study Lawless and Kulikowich (1998) tried to shed light on the interaction of domain knowledge and different navigational profiles as identified by literature review. The study identified "feature seekers" who got more easily distracted by special features of the hypertext environment and represented learners with little domain knowledge. Accordingly, individuals trying to maximize knowledge acquisition and endowed with some domain knowledge, were termed “knowledge seekers”. The “apathetic hypertext users” they claimed often to be dissuaded from engaging in an exploration of the text as these individuals were found to possess the highest amount of domain knowledge. MacGregor (1999) supported these findings identifying cognitive similarities of each profile with “concept connectors” possessing a higher level of prior knowledge than “sequential studiers” and “video viewers”.

While navigation provides a certain amount of learner control, the building of information sequences within multimedia environments may be particularly difficult for learners with limited prior domain knowledge. The cognitive theory of multimedia learning (Mayer 2001) presumes that prior knowledge can influence the construction of both verbal and pictorial models. It is claimed that a dual presentation is particularly valuable for persons with low prior knowledge.

Research and practice show that it is important to adapt the to-be-learned content to the prior knowledge of the learner. The linkage between design and further processing of information is also described by the elaboration likelihood model (ELM, Petty & Cacioppo 1986). The model focusses on attitude change by persuasion. An intensive elaboration of information takes place only if the recipient of a message is interested in the issue and has the ability to process the content of the information. This ability depends on the availability of cognitive resources and relevant prior knowledge. Ludwigs (2006) suggests to develop an ELM with a focus on computer-based learning.

1.2.1.2 Visual spatial ability

The visual spatial ability of the learner can have a considerable effect on navigation in hypermedia environments and the understanding of multimedia material (Wu & Shah 2004, Plass et al. 2003; Nilsson & Mayer 2002; Chen & Rada 1996) as mental model construction is very much related to spatial cognitive processing (Sims & Hegarty 1997). Recent research suggests that spatial ability may have an especially important impact when pictorial and animated 3D-visualizations are used for navigation or content presentation (Keehner et al. 2004; Wu & Shah 2004). Hays postulated that spatial ability can improve through instruction, Mayer (2001) however stresses that additional research is needed to pinpoint its role in multimedia learning.

Two contrasting hypotheses have been proposed regarding the benefit complex graphical presentations can offer learners with differing visual spatial ability:

a) the ability-as-enhancer hypothesis (Mayer 2001) claims that especially learners with high spatial ability profit from complex visualizations. It thereby builds on the cognitive theory of multimedia learning. The latter claims that the synchronisation of pictorial and verbal information is considered particularly valuable for individuals with high spatial ability (Mayer 1997) whereas individuals with low spatial ability are assumed to have to invest more cognitive resources to construct mental pictures.

b) the ability-as-compensator hypothesis of Hays (1996) contrasts the above by stating that especially learners with low spatial ability should benefit from complex graphical visualizations such as animations as the latter is assumed to better support them in the construction of mental images.

The ability-as-compensator hypothesis is supported by results of Plass et al. 2003. Also in line with this hypothesis are the findings of recent research on prior domain knowledge (Kalyuga et al. 2003): the study showed that novices to a subject area profited from the presentation of the identical information in two different presentation modes. For the expert learners however this presentation mode apparently represented additional (unnecessary) cognitive load.

As stated above, different studies show that in learner-controlled hypermedia environments spatial ability exhibits an influence on navigation and overall software use (e.g. Keehner et al. 2004; Steinke et al. 2004; Nilsson & Mayer 2002). Chen and Rada (1996) suggest that high spatial ability may support fast comprehension of a subject's domain structure. Results of Nilsson & Mayer (2002) showed a more efficient navigation when learners possessed high spatial ability. Steinke et al. (2003d) showed that users with low spatial ability invest more time in exploring movies and 3D-features than high spatial ability learners. Against the background of the ability-as-enhancer hypothesis the results outlined may be explained by a higher cognitive load for the low spatial ability group in processing pictures. Thus they may also need more time to deal with these features.

One navigation profile identified by different authors (e.g. Lawless et al. 2002) is the feature explorer. According to Lawless and Kulikowich (1998) this profile represents mainly users with low prior domain knowledge. In line with the above it seems likely that this profile may also characterize many learners with low visual spatial ability appreciating the possibility to interact with 3D-features. Results of Keehner et al. (2004) support this interpretation: in their investigation the learning performance of individuals with high and low spatial ability could be brought closer together by the possibility to manipulate a 3D-model.

1.2.1.3 Cognitive and learning style

In accordance with the cognitive models outlined earlier, it is generally agreed that the manner in which individuals approach a learning situation has an impact on performance and learning outcomes (Cassidy 2004; Yong 1998; Lee & Lehman 1993). Investigations of student learning preferences have shown that among the variables that influence the success of learning, e.g. gender, age or prior experience, learning style is considered particularly important (e.g. Ford and Chen 2000). Previous research indicates that students with different cognitive and learning styles exhibit different learning preferences and require different navigational support in hypermedia systems (e.g. Efaw & Bailey 2004; Graff 2003; Ford & Chen 2000; Reed et al. 2000; Liu & Reed 1995). Studies that examine the impact of cognitive and learning styles are seen to become paramount for such evaluations are believed to provide concrete prescriptions for developing learner-centred systems that can match the particular needs of different learners (Ghinea & Chen 2003).

Definition of cognitive and learning style

Researchers investigating learning styles are often daunted by the multitude of definitions, models and instruments available and a review of literature reveals that the terms "cognitive style" and "learning style" often seem to be used interchangeably (e.g. Desmedt and Valcke 2004).

Cassidy (2004) defines cognitive style to represent an individual's typical or habitual mode of problem solving, thinking, perceiving and remembering, while the term learning style is adopted to reflect a concern with the application of cognitive style in a learning situation. Riding and Rayner (1998) define cognitive styles as individually preferred and habitual approaches to organizing and representing information (see also Sonnenwald & Li 2003; Ford & Chen 2000). This is contrasted by a number of authors who regard the cognitive style as one significant component of a learning style. To this end Paolucci (1998) describes the technical difference between the terms in the following manner: "Cognitive style deals with the "form" of cognitive activity, i.e. thinking, perceiving, problem solving, etc. not its content. It is viewed to be a "persuasive dimension" of personality, bipolar in nature and stable over time. Learning style on the other hand is seen as a broader construct which includes cognitive along with affective and physiological styles."

A number of instruments have been developed to measure learning and cognitive style. In the following some of the more prominent instruments commonly used in hypermedia evaluations will be highlighted (for a comprehensive overview on instruments see Cassidy 2004).

Kolb's Learning Style Inventory (LSI)

Kolb's Learning Style Inventory (Kolb 1976) measures an individual's preference for two dimensions of learning. The first dimension is constituted by the two poles "abstractness" (abstract conceptualisation (AC)) and "concretness" (concrete experience (CE)). This is supposed to illustrate an individual's preference to perceive the environment or grasp experiences in the world. The second dimension consists of the poles "action" (active experimentation (AE)) and "reflection" (reflective observation (RO)). The latter is seen to illustrate an individual's preference to process or transform incoming information (Kolb 1984). The four extremes represent the poles of a four-stage cycle of learning. Relative positioning along these dimensions defines the learning styles described by Kolb as convergence, divergence, assimilation and accomodation (see also figure 2):

- convergers use abstract conceptualisation (AC) to drive active experimentation (AE). Their action is based on abstract understanding and they tend to focus on the heart of things;
- divergers combine concrete experience (CE) with reflective observation (RO). They are often described as creative learners who are particularly well-adapted to viewing learning situations from multiple perspectives;
- assimilators favour abstract conceptualisation (AC) and reflective observation (RO). They are described as thinkers specialized in inductive reasoning and the formulation of theories;
- accomodators use concrete experience (CE) and active experimentation (AE) and have a clear preference for hands-on learning. They are considered to rely on intuitive trial and error approaches to solve problems, and are highly adaptive to new situations.

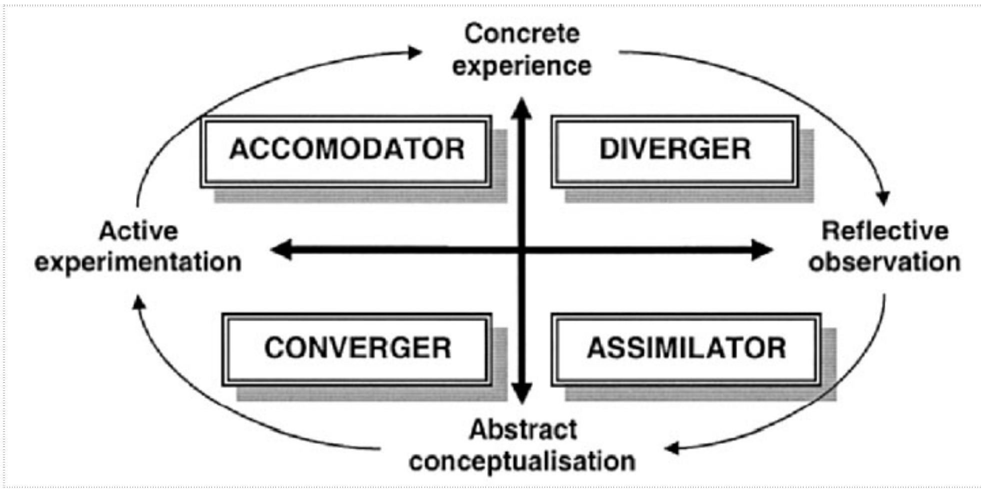

Figure 2 Kolb's learning styles (in Anis et al. 2004, adapted from Kolb et al. 1999)

As the two learning style dimensions are measured on two continuous scales an individual can lean more or less to one of the four learning styles. Dillon & Jobst (2005) provide a brief overview of some studies using the LSI as an instrument to investigate the impact of learning style on hypermedia use, and showing more or less strong interactions between system design (i.e. level of learner control, hypermedia structure) and learning style.

Witkin's field dependence

One of the most widely accepted approaches to studying cognitive style is the Witkin`s field dependence model (Witkin et al. 1977): with the Group-Embedded Figure Test (GEFT) examinees are classified as field-dependent, field-independent and field-mixed. GEFT requires participants to identify a simple figure within a more complex pattern. People who easily identify the simple figures are said to be more field-independent, those who find it difficult to extract the pattern from the field are classified as field-dependent. Castelli et al. (1998) describe cognitive field-independence as the general skill to isolate an element from its (physical, conceptual, social, etc.) context and employ it on its own or in another field. Witkin postulated that the ability to dis-embed simple figures from complex designs is reflected in the ability to solve a cognitive problem by isolating the critical element and using it in a different context. In the following a brief description of field-independent and field-dependent learners according to Witkin's model shall be provided (see also Cassidy 2004):

- Field-independent learners are characterised as operating with an internal frame of reference, intrinsically motivated with self-directed goals, structuring their own learning, and defining their own strategies.

- Field-dependent learners are characterised as relying more on an external frame of reference, are extrinsically motivated, respond better to clearly defined performance goals, have a need for structuring and guidance from the instructor, and a desire to interact with other learners.

A field-independent person is said to be capable of a more analytical cognitive functioning than a field-dependent person who may use a more global approach (Witkin et al. 1977). A number of authors (e.g. Ghinea & Chen 2003; Riding & Sadler-Smith 1992) have taken the model further claiming that the distinction between field-dependent and field-independent individuals is similar to holist/ serialist approaches to learning as proposed by Pask (1976). Field-dependent learners typically perceive objects as a whole and aproach a task more holistically; field-independent learners focus on individual parts of the object and tend to be more serialistic in their approach to learning (Chen & Macredie 2004). Moreover field-independent individuals are said to more likely use active cognitive strategies, whereas field-dependent individuals are described to have a tendency to use passive strategies (Frank & Keane 1993).

Different studies have shown correlations between field-dependence and learning behaviour in Web-based instructional programmes (e.g. Kim 2001; Chen & Ford 1998; Chou & Lin 1998). Results from these studies suggest that different cognitive style groups use different learning strategies in hypermedia instruction and therefore need different features to support the learning process. Figure 3 shows a design model of hypermedia instruction (Chen & Macredie 2004) and illustrates different support possibilities for field-independent and field-dependent learners.

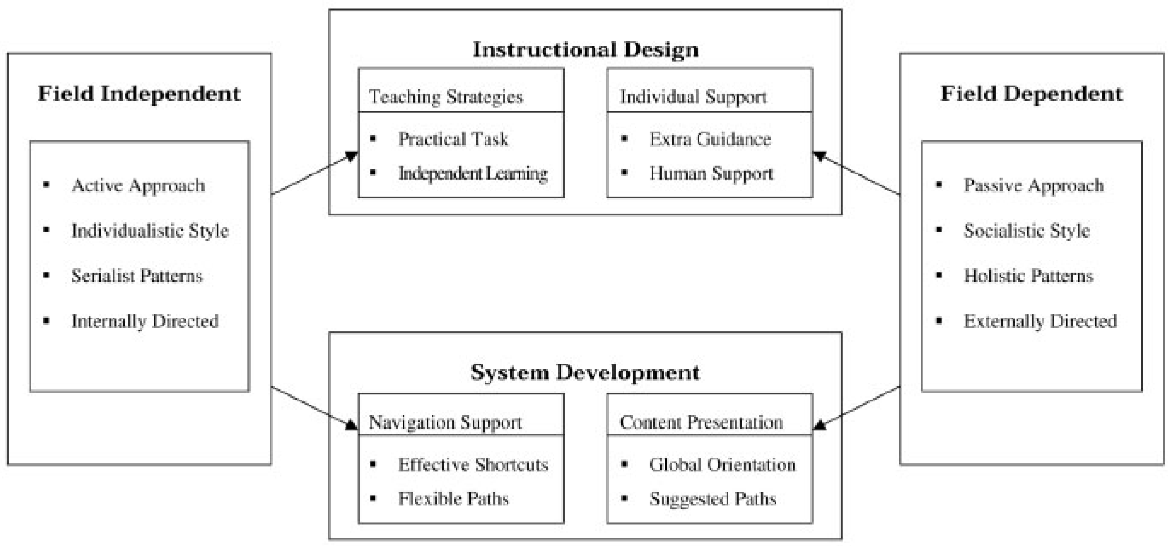

Figure 3 Design model of hypermedia instruction (in Chen & Macredie 2004)

1.2.1.4 Computer literacy

Literature review reveals that the level of computer literacy or system expertise of the users exhibits an impact on learning with hypermedia.

Different studies report e.g. an influence of computer-related experience or experience with the use of hypermedia on navigation behavior (Mitchell et al. 2005; Ford & Chen 2000; Reed et al. 2000; Reed & Oughton 1997). Specifically, Reed et al. (2000) investigated to which extent the prior computer-related experience predicted linear and non-linear navigation when using a hypermedia learning environment. In addition to the assessment of prior computer-related experience in general they differentiated skills such as authoring experience, use of data bases, use of hypermedia, programming, use of word processing as well as spreadsheet programmes. The study moreover showed a differentiated picture of the impact of computer literacy on navigation behaviour: differences in PC literacy indeed led to different navigation patterns, for example users with more programming and authoring experience were less likely to use non-linear steps than those with more word-processing or spreadsheet experience.

A number of studies support this view showing that hypermedia experience seems to enhance hypermedia-related metacognition which is reflected in a higher proportion of non-linear steps and results in a more efficient use of the hypermedia programme (Horz 2003; Reed et al. 2000; Reed and Oughton 1997). Moreover, from the perspective of the cognitive load theory there is a high probability that users with less system expertise or hypermedia experience suffer from more extraneous load when using non-linear software (Kalyuga et al. 2003; Paas et al. 2004). However and as outlined above, through training performance of learners may improve (see e.g. Frey et al. 2003).

1.2.2 Individual and collaborative learning

These last years research on computer-supported collaborative learning has gained popularity (e.g. Prangsma et al. 2008). It is acknowledged that many design challenges may need to get addressed to develop collaborative scientific discovery learning environments (Naidu & Järvelä 2006; Van Joolingen et al. 2005). When investigating the impact factors on learner activities in collaborative learning situations an important issue to consider is the influence of interaction between learners on the knowledge aquisition process and the learning outcome. As social and cognitive processes are sustained in a different manner during collaborative learning, various authors conclude that the principles of cognitive load theory which originally refer to individual learning need to be adapted to the design of collaborative learning environments (see e.g. Dillenbourg 2006; Kester & Paas 2005).

In the field of collaborative learning research so far a number of contradicting and often surprising research results have been reported. E.g. Schnotz et al. (1999) comparing the impact of static and animated pictures on learners working individually or in dyads, found that animated displays seemed to present an advantage only in the individual learning setting. These findings are challenged by Sangin et al. (2008) who on the contrary claim that animated pictures had a positive effect only when students were working in dyads.

Bartholomé et al. (2006) as well as de Lièvre et al. (2006) investigated the impact of independent variables such as prior knowledge and epistemological belief on the help-seeking behavior of dyads in a hypermedia learning environment. Contrary to expectations the findings suggest that dyads use the help function more frequently than individuals.

Moreover, Sangin et al. (2008) investigated the effect of snapshots that should reduce memory load and concluded that the latter benefits only individuals while they are detrimental to dyads.

Research findings support the conclusion that in hypermedia group learning situations special types of load may need to be taken into account. Dillenbourg (2006) refers to “collaborative load” combining several factors such as cognitive load and social interaction processes in an unknown way (see also Naidu & Järvelä 2006; Roschelle & Behrend 1995).

Yet mechanisms need to be developed to transfer the findings of investigations on individual cognition and learning to help understand cognitive processes in group learning situations. Against this background Dillenbourg (2006) concludes that further research in both settings is necessary.

The contradictions between empirical results on individual and group learning might contribute to better understand the possible linkage between individual cognition and social interactions. To this end the study presented aims to support research in the field by comparing impacts of software design features on students learning individually and in groups.

1.3 The software

In addition to the learners’ abilities, knowledge and experience the software, i.e. its design, is likely to influence the learning performance (e.g. Potelle & Rouet 2003; Barab et al. 1997). Against this background hypermedia environments should be evaluated by users to ensure that the respective software supports optimal learning processes and outcomes at the same time accommodating the need to make the systems user-friendly and enjoyable (Angeli et al. 2003; Hassenzahl et al. 2003; Saxena et al. 2002; Anjaneyulu et al. 1998).

Evans et al. (2004) claim that so far many online courses consist merely of a series of textual notes and pictures with little navigational information or choice. They postulate that in fact most of the currently available material is based on a number of usability and interactivity misconceptions. Stanton and Baber (1994) argue that disorientation is the by-product of poor interface design, i.e. users become "lost" because it is unclear what actions they can perform. Tripp and Roby (1994) state that disorientation will increase cognitive load which in turn will reduce the mental resources available for learning (see also Schroeder & Grabowski 1995).

Adaptive hypermedia

Many authors recommend using adaptive hypermedia systems. Currently, there are two main classes of hypermedia adaptation: adaptation at content level (adaptive presentation) as well as at structure level (adaptive navigation support) (Brusilovsky 1998). Magoulas et al. (2003) recommend using individual differences (e.g. different learning styles) as the basis for adaptation in hypermedia systems. They propose adaptation possibilities on several levels enabling the software to be used in a range of ways from full system-control to full user-control. Brusilovsky (2003) supports this approach describing the appreciation of users with different knowledge levels to be offered different adaptive navigation support technologies. Users with little or no knowledge of the subject area are best supported by restrictive technologies that guide them through the software adaptively limiting their navigation choice. In contrast, users with a solid knowledge in the subject area profit more from "rich" linking technologies, such as adaptive annotation and multiple link generation. Most e-learners therefore complain about a "one-size-fits-all" philosophy that results either in cognitive overload or underload and consequently does not support the personalization of existing applications (Rumetshofer & Woss 2003). However, most of the times a software programme is available only in one design version, ie. the version the designer feels most comfortable with. This approach ignores the fact that learners differ and perceive and process information in very different ways (Papanikolaou et al. 2003).

Research and the development of design principles

Liu et al. (2002) describe instructional design as a systematic process of translating principles of learning and instruction into plans for instructional materials and activities. So far however guidelines for interactive multimedia design do not seem to be based on empirical evidence but rather on the intuitive beliefs of designers only (Lowe 2004; Park & Hannafin 1993). According to MacGregor (1999) research on the design of hypermedia systems is in its infancy and few design principles have been established. Moreover, contradicting results do not facilitate the development of such principles. Zahn et al. (2004) e.g. highlight that different and even conflicting design strategies may be derived from research on multimedia and hypermedia learning: According to the principles of spatial and temporal contiguity of presentations as outlined in multimedia research one should integrate hyperlinks sequentially into videos, i.e. in spatial and temporal proximity to the visual "anchor" information. In contrast, taking the hypermedia research perspective and considering hyperlinks not only as means to connect different pieces of information but also as interaction tools between learner and medium hyperlinks should rather be presented as small clusters at the end of video scenes (see also Zhu 1999).

Against this background research focuses on the effects of different navigation tools and software design features e.g.the content structure, the presence/absence of maps (e.g. Müller-Kalthoff & Möller 2005; Gaus & Urbas 2003; Farrell & Moore 2000-2001; Chiu & Wang 2000; Möller & Müller-Kalthoff 2000), learning support features (Gerjets et al. 2005; Winter et al. 2003; Burke et al. 1998) and the impact of different content design (e.g. Brünken et al. 2005; Rouet et al. 2004; Huang 2003; Ghinea and Chen 2003; Stiller 2001) on navigation behavior and learning outcome. In various studies learner characteristics e.g. prior knowledge or learning style are also taken into account. Recent research has furthermore focused on alleviating the problem of the user becoming lost while using hypermedia (Mullier et al. 2002). Moreover, Szabo and Kanuka (1998) stress that much research has been undertaken regarding the use of text, colour and graphics, including topics such as text density, text size, line length, margins, columns, location of information, colour choices and the use of graphics (in motion or static).

Analysing investigations on hypermedia systems however a variety of factors hindering comparability and generalizability have to be taken into account (Möller & Müller-Kalthoff 2000).

Improving instructional design or developing adaptive hypermedia does not automatically result in improved performance unless it is accompanied by profitable strategies of information utilization (Gerjets & Scheiter 2003). Therefore more research on this topic is necessary.

1.3.1 Navigation tools and information search

Due to the manifold navigation possibilities to be followed by the user, navigation design is considered one of the most critical challenges when developing hypermedia learning systems (e.g. Smith & Ng 2003; Schulmeister 2002; Calvi 1997). The World Wide Web can be considered as one huge hypermedia environment. The navigation design of such environments has to answer three fundamental questions of the user: Where am I? Where have I been? Where can I go? (Smith & Ng 2003; Nielsen 2000; Navarro-Prietro et al. 1999). An important hypermedia design issue therefore concerns the way in which the information should be organized and how it should be accessed in order to avoid/limit disorientation of the learner. To this end navigational aids, for example maps, are introduced to facilitate orientation and reduce cognitive load in hypermedia learning environments (see Conklin 1987). Various studies (e.g. Potelle and Rouet 2003) add to a growing body of evidence that in this area more is not necessarily better: Castelli et al. (1998) showed that introducing more and more sophisticated navigation mechanisms into the hypertext bears the risk that the users' attention will be diverted from informational features to navigational ones. Moreover simpler navigation tools in hypermedia environments may prove more learning effective to users with lower prior knowledge (see also Möller & Müller-Kalthoff 2000; Hofman & van Oostendorp 1999).

According to Graff (2003) two of the principal issues to consider assessing whether a system facilitates the users' learning are a) the segmentation of information and b) the means to provide the user with an overview of the system. Evans and Edwards (1999) categorize the structure of educational hypermedia into three basic types: linear, hierarchical tree and network or directed graph. They also mention three types of navigational tools that might be used: sequential (unidirectional), menu (multidirectional), and map (omnidirectional). Navigation tools determine the scale of interactivity and learner control of a hypermedia learning environment (see also Leung 2003; Burke et al. 1998).

Planning the navigation in a hypermedia learning environment important issues to reflect on therefore refer to the tools to use, for example index, site map or search machines. Various studies support the view that a high variation of navigation tools and access possibilities might lead to a better acceptance of the software by the users (see e.g. Chen & Macredie 2002). An alphabetical index may for example better support learners who tend to be analytical, a site map may better support learners who prefer to process information in a global fashion (see also subsection on cognitive and learning styles). Therefore, many hypermedia systems today provide multiple navigation tools such as map, index and menu to allow users to structure their navigation strategies according to individual taste and need.

Navigation design and navigation aids

Besides the possibility to offer navigation aids as a map and/or a graphical overview (see below) users can be led through the system with the help of content-based navigational design techniques, for example through pictures or a table of contents/index (see e.g. de Roure and Blackburn 2000). Studies of Stiller (2001) as well as Ballstaedt (1997) arrive at the conclusion that navigation by pictures constitutes an effective method to foster picture processing. However, no differences concerning learning outcome could be shown and moreover studies suggest that pictures present some additional cognitive challenges. It is assumed that this type of navigation occupies some processing capacities thereby reducing the resources for semantic processing (Sweller & Chandler 1994).

Other navigation aids include backtracking, history lists, paths, structure-based queries, timestamps, footprints, fisheye views, annotations, pre-structured links, embedded hotwords etc. (e.g. Madrid et al. 2009; Chiu 2004; Leung 2003; Ji & Salvendy 2002).

A study of Beasley and Waugh (1995) on the effects of hotwords, spider maps and hierarchical maps in a hierarchically-organized hypertext revealed that learners using the hierarchical map felt significantly less disoriented than the learners using the hotwords. These results suggest that when a learner's attention is at least partially focused on the structural aspects of a hypermedia module disorientation will decrease. To this end also Danielson (2002) examined user movement through hierarchically-structured web sites and showed that users being provided a site overview performed better in information-seeking tasks.

Calvi (1997) as well as Rouet et al (2001) furthermore found that users appreciate the provision of a content list as well as a map and consider them to represent two complementary cues.

Graphical overviews / sitemaps

Many authors consider graphical overviews as an indispensable navigational aid (e.g. Müller-Kalthoff & Möller 2005; de Jong & van der Hulst 2002; Chou & Lin 1998). They postulate that hypermedia environments should not only take into account the overall exploration pattern of learners but support the learner with graphical overviews linking the latter to deep representations of the domain. Moreover these authors believe that digital mindmapping systems can be used for promoting the development of cognitive and meta-cognitive strategies (Graeber et al. 2004). However, the benefit of graphical navigation overviews is challenged in a multitude of studies (Gauss & Urbas 2003). Some studies indicate that maps do not necessarily help navigation and reduce disorientation (Leung 2003) and different experiments showed that offering navigational aids such as a map did not support better understanding and memorizing of learning material (e.g. Dias & Sousa 1997).

Against this background the question arises how maps have to be structured to sustain navigation and learning appropriately. In spider maps, the central concept is surrounded by its related sub-concepts. In hierarchical maps on the other hand the central concept is situated above its subordinate concepts. Findings of a study of Beasley & Waugh (1995), along with the results of Stanton et al. (1992), provide strong evidence that the inclusion of spider maps in hypermedia systems that are organized hierarchically does not reduce disorientation in the learner and in some cases may even increase it. A study of McDonald and Stevenson (1999) showed that navigation was best with a spatial map whereas learning was best with a conceptual map. In a study of de Jong and van der Hulst (2002) a hypertext environment was enhanced with a graphical overview that represented the structure of the domain and the layout was designed in such a way that learners were unobtrusively encouraged to follow a sequence of exploration that followed the domain structure. This design was compared with two layouts that presented randomly positioned nodes, one enriched with highlighting hints to stimulate learners to follow an exploration similar to the structured layout. Results of the investigation showed that propositional and configural knowledge gain was significantly higher when a structured map or a map with highlighting hints was provided.

Regarding the structure of the map there are two levels of overview diagrams: global and local (Nielsen 1990). Global overview diagrams provide a coarse-grained picture of the hypermedia network and can also provide access to local overview diagrams. Local overview diagrams provide a fine-grained picture of the local neighbourhood of a node (Chiu 2004). The goal of a study of Chiu & Wang (2000) was to determine the optimal scope of a navigation map ("global" vs. "local") in hypermedia courseware. The findings suggest that a navigation map should not exhibit too much detail but on the other hand not necessarily present global information, i.e. covering the whole content of the hypermedia environment.

Hyperlinks

Additionally to the structure of the material and the types of navigational tools the use of implicit hypermedia links adds another dimension to the design of hypermedia. Their importance lies in their utility for reference rather than learning (Evans & Edwards 1999). Schweiger (2001) states that a user-friendly hypermedia design implies that links are not integrated sequentially, but rather more globally as clusters to certain navigation areas where they may be surveyed and selected more easily (see also Zhu 1999). Zahn et al. (2004) moreover state that there are very few guidelines on the structure of hyperlinked videos available.

Research on navigation tools

Research on hypermedia learning systems has focused on the relative effects of the different navigation tools used for browsing (Beasley & Waugh 1996). These effects have been studied predominantly through performance measures such as speed, accuracy, number of pages accessed and recall of document elements (Boechler & Dawson 2002). To evaluate the navigation strategies the students' paths are often tracked by means of logfiles. As Chavero et al. (1998) put it, a record on how the students navigate is believed to represent a good mechanism to compare reality with expectations when developing a programme. Accordingly, knowledge regarding the way information-seekers in hypermedia environments behave with respect to the structures and cues they are provided with, is believed to support shedding light on general principles of navigation in hypermedia environments, and assist designers in making more informed decisions (Danielson 2002).

A number of innovative tools have been piloted and evaluated by developers and researchers including guided tours (e.g. Anjaneyulu 1998), three-dimensional graphical browsers, keyword searches, and concept maps (eg. Hilbert & Renkl 2008; Beasley & Waugh 1995). Interactive menus and concept maps are used to represent gist concepts and their relationships (Potelle & Rouet 2003). Gerjets, Scheiter and Schuh (2005) tested whether guiding improves learning outcomes by reducing control demands and by increasing utilization of provided examples. Results showed that presenting the learning material as a guided tour compared to non-linear hypertext increased duration on the sample sites but not problem solving. The study therefore seems to support the hypothesis that the non-linear content presentation may be the more advantageous concept as learners seem to get the same learning outcome in less time. Logfile analyses moreover revealed that exactly those navigational patterns that corresponded to the profitable cognitive processes of comparing and elaborating examples were associated with better learning and transfer performance.

1.3.2 Learning support tools

Types of help tools

Leung (2003) describes three major types of learning help tools: Just-in-time support provides hints, clues, concepts to reflect on or contextualized support to help learners as they progress. Scaffolding is used to facilitate the transfer of what users already know to the task at hand. By coaching additional resources are made available to learners as they progress through the to-be-learned material. This includes directing learners' attention, reminding them of overlooked steps, providing feedback, challenging the learners and suggesting structured approaches to do things as well as providing additional tasks.

Feedback

Feedback can help learners to improve the learning process and outcome. It can be provided visually, verbally or in both formats (Leung 2003). A number of studies shows that feedback should involve more than confirmation of the accuracy of a response: Moreno (2004) e.g. investigated the impact of different feedback forms and the findings suggest that explanatory feedback designed to provide learners with further guidance increased test performance and decreased ratings on task difficulty. Rieber et al. (2004) explored how adult users interact and learn during an interactive computer-based simulation supplemented with brief multimedia explanations on the content. Results showed significant differences for both the use of multimedia explanations and simulations containing graphical feedback in helping participants gain both implicit and explicit knowledge.

On-demand help systems

On-demand help systems such as context-specific hints, hyperlinked background materials or online glossaries prove to be very helpful to students (Aleven et al. 2003). Another possibility to sustain learning is the possibility to take notes while working with a hypermedia environment. This allows users to add information and thoughts during the process of knowledge acquisition (Chiu 2004). Also Brünken et al. (2003) postulate that tools supporting comprehension of the to-be-learned content enhance coherence formation in the learner. Betrancourt and Bisseret (1998) suggest that in complex interactive environments where the integration of both large texts and pictures in a single computer screen is difficult cognitive load might be reduced and thereby learning outcome enhanced by the integration of interactive elements such as pop-up fields. Another possibility to support problem solving in a hypermedia environment is the provision of worked-out examples. Studies introducing prompts to elicit a more intensive elaboration of the relation between abstract information and examples showed that the prompts led to improved problem solving (see e.g. Gerjets et al. 2005).

1.3.3 Content design

Apart from navigation properties the instructional value of a hypermedia learning environment depends on the value of its single components such as their graphical and didactical presentation. These components might be defined as content modules which represent the nodes within a hypermedia system and usually can contain a broad bandwidth of media and forms of representations, for example texts, graphics, static pictures, animations, simulations, video, narration and sound. The definition of content modules as nodes implies that these are clearly separated from the surrounding hypermedia environment and especially from navigation features. Depending on the individual application however often there is no clear distinction between content and navigation system.

Paolucci (1998) e.g. showed the positive correlation of adequately structured content presentations and learning performances. Zhu (1999) found a significant effect of the size of information nodes on information searching. The way information is structured is also important in relation to the kind of task to be performed as well as the strategies the users are likely to apply (see e.g. Beasley and Waugh 1997). Against this background it seems advisable that software designers including teachers and lecturers producing multimedia learning material should intensively reflect on the instructional design of modules.

<u>Virtual reality and 3D-models</u>

Many publishers are now using web-based games as a powerful way to simulate and educate (Stewart 1997). Moreover, many types of virtual reality systems and simulations are in use which may be described by the grade of "immersion" of the user in the content area (Freeman 1997). Heers and Schwan (2003) postulate that the use of virtual realities can sustain knowledge acquisition processes effectively (see also Nicaise 1998).

Navigation within a hypermedia environment can also extend to single content modules, i.e. complex virtual 3D-objects or models. The latter may necessitate the provision of additional support and guidance to users (Noser et al. 2004). Learning with simulations is viewed as essentially exploration-based and is considered to stimulate problem solving, discovery learning or inductive learning processes (Goodyear et al. 1991).

Static visualizations

Over the last two decades research has shown that static visualisations offer various benefits to learners such as computational offloading and graphical constraining (e.g., Larkin & Simon 1987). However, on the learner they also impose processing costs in terms of specific requirements for mentally selecting and organising visually presented information (see e.g. Schnotz & Bannert 2003; Mayer 2001). Although the psychological processes involved in learning with static visualisations are not yet fully understood (Scaife & Rogers, 1996), theoretical frameworks such as Richard Mayer's theory of multimedia learning (Mayer, 2001) and John Sweller's theory of cognitive load (Sweller & Chandler 1994) have helped to stimulate a more informed debate about how static visualisations should be used in educational materials (Ploetzner & Lowe 2004).

Dynamic visualizations

Following multimedia learning principles knowledge acquisition can potentially be facilitated by dynamic visualizations or by a combination of different presentation formats (Mayer 2001), the latter frequently combined with the possibility of modifying them interactively (Bodemer et al. 2004). Accordingly, many educational multimedia and hypermedia products include sophisticated pictorial material and dynamic visualisations. The latter are appreciated to directly present - in contrast to static pictures- changes in space over time (Ploetzner & Lowe 2004). Dramatic advances in computer technology have improved methods and tools for interactive 3D-modelling (e.g. Johns & Brander 1998), in some cases even providing haptic interfaces (Sonnenwald and Li 2003).

Animations as one type of dynamic visualization are defined by Park and Gittelmann (1992) as artificially generated movements of pictures or graphics in computer displays, resulting in apparent motion. Schnotz and Lowe (2008) define them as dynamic visual representations where the information about temporal change is contained in the difference of object properties between successive frames. With the increasing use of quality animations in many interactive multimedia programmes, more detailed analyses on the needs of the learners in general, the learning tasks requiring dynamic visualizations, and the appropriate use of these visualizations in multimedia instruction are called for (see also Hays 1996). Many authors moreover highlight that the effectiveness of dynamic visualizations in learning software seems highly dependent on the type of task to be tackled (de Westelinck 2005; Hegarty 2004; Schwan & Riempp 2004; Hegarty et al. 1999; Hays 1996; Park & Gittelmann 1992).

Currently, intuition and artistic judgement appear to be the dominant guiding forces when designing animations: little empirically-based information exists regarding what characteristics of an instructional animation are potentially beneficial to learners or whether learners appreciate them at all (Lowe 2001). Gerjets and Hesse (2004) moreover point out that multimedia technologies like hypervideos, animations or virtual realities may in fact effect learning negatively as these technologies can be used rather passively for information, entertainment or relaxation with learners expecting that no effortful deep processing is necessary. Designers of educational animations may therefore be well advised to design a more proactive role to the users in manipulating content presentation so that it goes far beyond a dynamic record of events (Lowe 2004).

While multiple, dynamic and interactive external representations have the potential to improve learning in various ways, they also place specific cognitive demands on learners, such as the need to process and relate corresponding elements and structures in different representations and to construct coherent mental representations (Brünken et al. 2005; Seufert 2003). Computer technology allows a high degree of learner control for the use of dynamic visualizations (Ploetzner and Lowe 2004). Thereby not only the balance between author and user is profoundly changed, but also the interplay of internal and external activities of the user (Schwan & Riempp 2004). Interactive animation that can be controlled by learners may allow the user to adapt its use to individual needs and thereby help to reduce the probability of information processing problems (Lowe 2004; Schwan & Riempp 2004; Burke et al. 1998). On the other hand the interface to control an interactive-dynamic display can also be considered a source of extraneous cognitive load (e.g. Sweller et al. 1998) as it diverts a part of the user's attention from the task at hand to understanding the control mechanisms. A number of authors (Brünken et al. 2005; Bodemer et al. 2004; Navarro-Prieto et al. 1999) are therefore concerned that the presentation of multiple, dynamic and interactive representations might not only not support but even impede the learning process by contributing to a cognitive overload. The design of effective interactive dynamic visualizations aiming to keep the extraneaous load minimal must therefore be informed by the research on human computer interaction (e.g. Saxena et al. 2002). However, when the information to be presented is complex, it is not always easy to bring together principles from human computer interaction with those from educational theory (in this context see Zahn et al. 2004). Therefore, questions on how to create effective natural interfaces that facilitate learning do not have simple answers (Hegarty 2004). Moreover, different studies (e.g. Lowe 2004; Zahn et al. 2004) provide evidence that learner characteristics have a higher impact on learning with interactive visualisations than media or interface design. Literature furthermore suggests that in order to build adequate mental representations from interactive animations, especially novice learners may need specific guidance regarding search strategies and targets (e.g. Lowe 2004).

When designing interactive dynamic visualizations the graphical and didactical design of the content is an important issue to reflect on. Moreover, the use of complex 3D-visualizations most often is associated with a significant increase in costs. Their integration in instructional software should therefore be justified by a more efficient learning process and better learning outcome. In this context a topic for further research seems to concern the question whether visualizations used for knowledge acquisition should be designed in a two- or three-dimensional way. A further research topic concerns the integration of cues or signals in animations.

As stated above, our understanding of how learners process dynamic visualisations is in its infancy (Ploetzner & Lowe 2004). At present, research is able to offer educational practitioners little principled guidance about what is required for the effective design and use of these representations. Under these circumstances, it is hardly surprising that most of the dynamic visualisation produced for today’s multimedia learning environments are designed and used on the basis of intuition rather than research-based principles and therefore tend to be simplistic and unlikely to take proper account of the complex nature of dynamic visualisations. Against this background there is a need for further research to examine the cognitive factors that are involved in learning with dynamic visualisations (see also Chandler 2004). The study presented strives to take account of this need: the study aims to capture the way users interact with dynamic representations and how their mental models develop during the course of that interaction.

Combination of content representations

Bodemer et al. (2004) e.g. revealed in their study that the active integration of different presentation formats improved learning significantly and that the structured interaction with different presentation types specifically increased verbal understanding. In another study Bodemer et al. (2005) showed that the active integration of static presentations before processing dynamic visualisations leads to better performance and can provide a basis for a more systematic and goal-oriented experimentation behaviour during simulation-based discovery learning.

1.4 The user-software interplay

A growing body of research documents the influence of learner characteristics, the study goal or learning task, the instruction provided and the software design on navigation and the knowledge acquisition process in general (see e.g. Opfermann 2008; Ghinea & Chen 2006; Gerjets & Hesse 2004; Rouet et al. 2004; Chen & Macredie 2002; Barab et al. 1997; Calvi 1997; Reed et al. 1997; Verheij et al 1996; Melara 1996). The knowledge on how design features and learner characteristics influence the selection of learner goals and processing strategies has to be rather specific in order to have any impact on improving outcomes when learning with multimedia and hypermedia (Gerjets & Hesse 2004). Studies on individual differences with significant effects on student learning in hypermedia systems include investigations on cognitive styles, computer experience and prior domain knowledge (e.g. Ford & Chen 2000, Reed et al. 2000 Lawless & Kulikowich 1998) or the effect of different navigation features (e.g. Farrell & Moore 2000-2001; Chiu & Wang 2000) on navigation behaviour and learning outcome. Naturally, motivation is seen as a critical element in learning processes (Unz 2000). A meta-analyis of Chen and Rada (1996) focused on three factors that seem to predominantly influence the use of hypertext: the cognitive styles and spatial ability of users, the complexity of tasks, and the structure in which information is organized as well as its visualization. They point out that the greatest effects are owing to the spatial ability of individuals.

1.4.1 User control in learning environments

Depending on their design web-based instruction in general and hypermedia environments in particular allow the user to a varying degree to interact with the programme and to control his or her own learning. Variables that can be controlled either by the user or the software include among others content, sequencing, pace, difficulty, learning control and feedback features. Schwan & Riempp (2004) claim that the impact of learner control depends on the interface design. Some software features even empower proactive individual learning and allow users to adapt presentations actively to their own cognitive needs (Schwan & Riempp 2004; Yong 1998). Different authors categorize the level of learner control in different ways. Goodyear (1991) considers three areas for learner control: control over the learning strategy, over the manipulation of content, and over the description of the domain. As mentioned earlier, Leung (2003) diversifies furthermore three levels of programme control, i.e. from guided by the programme to direct user control.

A number of authors postulate that more user control in computer-based learning can motivate users and potentially improve learning effectiveness. In fact MacGregor (1999) stresses the high degree of learner control to present one of the major advantages of hypermedia learning environments. Results of a study of Burke et al. (1998) e.g. reveal that students who control the sequence of their instruction deviate from a linear path significantly more often when provided with navigational aids. Furthermore, this study's findings suggest that the possibility to navigate freely through the programme is associated with better learning performance as well as a significantly more positive evaluation of the software by the respective users.

These findings are challenged by the view that more user-control, such as interactive features, may also increase the cognitive load of users, causing disorientation and even hindering learning (Leung 2003, Sweller et al. 1998). A study of Opfermann (2008) also concludes that low levels of learner control seems more beneficial than high levels, regardless of prior knowledge. However, research on human-computer interaction indicates that interactive functionalities can be designed in a way that keeps extraneous load increase at a low level (Schwan & Riempp 2004). With sufficient and appropriate navigation aids and online learning help, taking different learner characteristics like the level of prior knowledge and learning style into account, users can have more control over their own learning and exploration without causing disorientation, and can thus improve their learning effectiveness (Leung 2003, Stanton & Baber 1992).

1.4.2 Learner characteristics and software use

Cognitive /learning style and software use

A multitude of studies suggests that the learning/ cognitive style exhibits an influence on how individuals use a software and thus that a certain content presentation format may be profitable for people with different cognitive or learning styles to a varying degree (see Angeli & Valanides 2004; Chen & Macredie 2002; Lee & Lehman 1993; Verheij et al 1996).

A further examination of the relationships between hypermedia's non-linear features and individuals' cognitive and learning styles therefore seems necessary if designers want to take full advantage of the ways these features can benefit learners (Lee et al. 2005; Chen 2002). Leader and Klein (1996) showed also a significant interaction between search tool use and cognitive style. Moreover, Ghinea & Chen (2003) add that research so far has neglected to examine the effect of cognitive and learning styles on users' subjective perceptions of multimedia quality. To this end research on individual differences should be conducted especially within more sophisticated 3D-multimedia environments as the financial implications of their development play a significant role. Against this background further empirical work is necessary to build robust user models for the development of "personalised" multimedia environments and to assess the validity of the models proposed so far (Cassidy 2004; Ghinea & Chen 2003).

When developing a hypermedia learning environment important issues to reflect on refer to the tools to use for navigation, e.g. index, site map, search machines, linkage structure and learning support, e.g. notes and glossary. A high variation of navigation tools, learning support tools and access possibilities might lead to a better acceptance by the users. This view is supported by various studies reviewed by Chen and Macredie (2004) recommending to take different learning styles into account when designing navigation support for hypermedia systems. An alphabetical index may for example better support learners who tend to be analytical, a site map may better support learners who prefer to process information in a global fashion. Therefore, many hypermedia systems today provide multiple navigation tools to allow users to structure their navigation strategies according to individual taste and need. In this context navigation features such as maps and learning support tools such as a glossary are considered important tools in the process of knowledge gain.

Research also reports an impact of learning styles on learning outcome and software evaluation by the users (see also Graff 2006). Moreover different researchers (e.g. Fitzgerald & Semrau 1998; Leader & Klein 1996) found differences in learning outcome dependent on the design of the hypermedia programme. Field-independent users were favoured when features of the hypermedia programme allowed learning approaches through indexing and searching strategies. Browsing or mapping approaches revealed no difference in outcome between users with differing field-dependency. Lin and Davidson-Shivers (1996) found that students with lower field-dependency adapted a more positive attitude when being offered less structured instruction. Other results (Chou & Lin 1998) suggest no differences in the search performance (student motivation, use of learning strategies) of field-dependent and field-independent learners when given a clearly defined task. This result is in line with Shih and Gamon (1999) postulating that students with different learning styles and backgrounds can learn equally well when learning with hypermedia.

Prior domain knowledge and software use

Learning aids seem especially profitable when they are linked to effective usage strategies, which in turn may be influenced by learner characteristics and software design (Gerjets & Scheiter 2003). In particular, many authors point to the impact of prior domain knowledge on the use of learning aids. The results of a study of Seufert (2003) indicate that for learners with insufficient prior knowledge instructional help is not always helpful or in case of recall performance even harmful. Learners with a medium level of prior knowledge can increase especially their comprehension performance when help is offered, whereas learners with considerable prior knowledge do not seem to be positively stimulated by being offered help tools.

A study of Möller & Müller-Kalthoff (2000) furthermore investigated the effects of offering a navigational aid to learners with different levels of prior domain knowledge (high vs. low). The results reveal an interaction effect of navigational aid and prior knowledge: availability of a navigational aid promoted better acquisition of knowledge of students with low prior knowledge. The findings are also supported by studies of Nielsen (1996), who claims that maps can be used especially well by beginners, who want to get an overview without being overloaded by detailed information.

One of the primary tasks of a designer of instructional software is to plan the instruction so that students can use cognitive strategies to learn the material actively. A website designer's challenge is to produce a non-author-centred architecture that doesn't stifle but stimulate learners' action (Applen 2002). Results of Sayers et al. (2004) indicate that the visual presentation of navigational aids improves navigation performance, in terms of the time taken to complete tasks, and also improves user satisfaction with the system. Various help tools should be provided in learning-oriented hypermedia applications and they should be made domain independent and maintain the user's freedom to explore. There is evidence that learners learn best in discovery approaches allowing the user to discover for themselves (see also Leung 2003). But the question remains if such discovery approaches are especially valuable for users with high prior domain knowledge. Therefore navigation aids can be especially important for users with low prior knowledge. Studies by McDonald and Stevenson (1998) and Dee-Lucas and Larkin (1999) showed that experts rely on their prior knowledge when interacting with a hypertext system, whereas novices rely more on cues in the interface (see also Lee and Lehman 1993).

1.4.3 Navigation paths, profiles and strategies

The individual's movement through learner controlled multimedia environments are commonly referred to as a learner's navigational path (Lawless & Kulikowich 1996). Burke et al. (1998) categorized the navigational paths of the students in learner-controlled conditions either as "linear" or "nonlinear". Based on a study of user navigation through interactive data-bases, Canter et al. (1985) describe five navigation strategies: scanning, browsing, searching, exploring, and wandering. Navarro-Prieto et al. (1999) identified three different general patterns of searching, a top-down strategy, a bottom-up strategy and a mixed strategy. Beasley & Waugh (1997) distinguished top-down and left-to right approaches and Stanton & Baber (1992) described the strategies as top down, sequential, and elaborative.

Students differ in the kind of navigation strategies they use. Some prefer to consider the content of the text or the externally provided directions when deciding how to proceed, whereas other students take the structure of the text or guidelines as a point of departure only (e.g. Cerdán et al. 2009; Verheij et al. 1996). Nielsen (2000) has shown in studies that more than half of the users are search-dominant (i.e. go directly to a search button), about a fifth are link-dominant (i.e. follow the links around the page), and the remaining individuals exhibit mixed strategies.

So far the cognitive processes involved in navigating through a single hypertext document, let alone a hypermedia environment are not understood clearly (Boechler et al. 2002). Recently, research has tried to shed some light on the correlation of navigation strategies and learning outcome and the findings of a study of Zahn et al. (2004) e.g. point to a strong correlation. Schwan and Riempp (2004) conclude that learners' navigation strategies present a critical factor in learning and that moreover strategic adaptations can compensate successfully for unfavorable instructional conditions (e.g. time pressure). Reed et al. (2000) investigated the linearity of navigation behaviour and postulate that learners using more non-linear steps take less time on the tasks. However, the question whether the latter also supports better learning outcome has yet to be answered.

As highlighted earlier a review of literature points to the strong role individual differences play for the software usage and the subsequent learning outcome. Various authors (Mullier et al. 2002; Lawless et al. 2002; Barab et al. 1996; Lawless & Kulikowich 1996) postulate that similarities of users with respect to navigation paths, usage patterns and usage time may be due to similarities of learner characteristics, such as prior experience or age. Against this background, research increasingly focuses on the user and his individual characteristics.

Castelli et al. (1998) identified seven possible categories of hypertext users considering the factors intellectual efficiency, analytical and synthetic capacity, analytical flexibility, abstract reasoning and cognitive field independence.

Several researchers have identified at least three common navigational profiles: MacGregor (1999) e.g. identified “sequential studiers” trying to infer their knowledge from sequential access to different objects, “video viewers” spending most of their time watching videos, and “concept connectors” exhibiting a high interest for further explanations. Moreover, a number of authors arrive at the following classification: (1) knowledge seekers (also referred to as book lovers), (2) feature explorers (also called resource junkies), and (3) apathetic hypertext users (see also Lawless et al. 2002; Lawless & Kulikowich 1998; Barab et al. 1997). Knowledge seekers typify those readers who pursue efficient information retrieval related to the contents of the software. Feature explorers are the user group that spends a disproportionate amount of time interacting with special features of a hypermedia environment. The individuals falling under this category invest more time in understanding how the programme works and what kind of screens it contains rather than trying to gather subject-related information. The apathetic hypertext users show little motivation to use hypertext nor to gather information. Accordingly, their navigational paths reveal no logical order.

Against the background of strong evidence pointing to the correlation of different usage patterns and strategies to improve or diminish learning outcome, the study presented aims to have a closer look at the factors which exhibit an impact on the usage of hypermedia learning environments. Apart from individual differences it is the instructional design of the learning environment that is investigated.

1.4.4 Logfile tracking

Usage behaviour and learning with computerized media can be investigated with a variety of methods including direct observations of the users, interviews, questionnaires, on-line-surveys and different methods to further process and analyze the data (see e.g. Schwan and Riempp 2004; Navarro-Prieto et al. 1999; Yong 1998). Rather than directly interviewing and questioning users, increasingly the learner variables are investigated less intrusively by observing the effects. Methods to this end include logfile tracking, think alouds or video recording (see e.g. Plass 2005; Davidson-Shivers et al. 1999; Calvi 1997).

Retrospective questionnaires and stimulated recall protocols have the potential to reveal certain patterns, but because they do not gather data as cognition happens, there is the possibility that learners misrepresent cognition and motivation by engaging in reconstructive processes (Winne et al. 1994). Think-aloud protocols may eliminate misrepresentations attributable to reconstructive recall, but they risk interfering with the very individual difference a researcher seeks to study.

Logfiles are undoubtedly the least intrusive method to get a better idea about the user acitivities in learner-controlled hypermedia environments. In literature logfile tracking is also referred to as recording time stamps or dribble files, data mining, protocol analysis or audit trails. Logfiles provide information on the overall activity of learners in a hypermedia environment such as time spent with different features, visited nodes and others. They can also be used to extract exploration patterns of participants with different learner characteristics, background and abilities. By this utilization and efficiency of learner-controlled multimedia environments can be evaluated (see also Hegarty 2004).

Nicholas and Huntington (2003) define log files as skeletal digital fingerprints that people leave behind when they search for information; they point out that there is a significant academic and commercial interest in their analysis. Carefully interpreted, such data provide important initial sketches of the information landscape which in turn form the basis for long-term analyses. Logfile tracking of the usage of a complex hypermedia environment can also be used commercially for science education in schools and universities and shall lead to a realistic overall picture of the learners' knowledge acquisition processes.

In hypermedia research, logfiles represent a useful source of information about users' navigational behavior (Richter et al. 2003). By log file tracking cognitive events can be traced by the observable actions that the learner performs. To this end Winne et al. (1994) define individual differences as cognitive acts that learners perform over the course of engaging with a task. To get a better idea about the impact factors on the learning processes, it is important to link the data captured in log files with independent variables, such as individual characteristics of the users or the software design as it was done in the present project. For their interpretation it is important to set logfile results against the background of other data such as the learning outcome, user statements or evaluations. To investigate profitable strategies of exploring and utilizing technology-based learning environments on a more detailed level one possibility is to calculate correlations between different learning outcomes on one hand and strategy measures derived from logfile analyses or verbal protocols on the other hand (Gerjets & Hesse 2004).

1.5 The research project

1.5.1 The CRIMP project

Creating a realistic learning scenario

„Our interpretations are limited by the fact that our presentation was short, involved only one passage, and did not take place in a classroom setting. Future research is needed to determine the generalizability of our results." (Mautone & Mayer 2001).

To develop a framework that can help to successfully integrate new media into formal and informal learning a lot of research has been carried out already. The goal is to best possibly adapt learning software to the needs of the users taking into account theoretical models on the limits of human cognitive capacity. To this end on one hand the instructional design research looks at the impact of the design of pictures and animations on learning. This is often done in experimental settings with single modules that are more ore less artificial. On the other hand many best practice studies are performed within the scope of daily work in schools and universities to find out under which circumstances certain software environments can sustain self- and teacher-guided learning. However, these studies are often unique in their design and therefore their findings are difficult to compare, let alone to take as the basis to develop any design guidelines.

Reasons for the missing interaction between the fields are seen in the different and almost incompatible theoretical and methodological viewpoints. However, a closer collaboration and coordination of these two research directions seems highly desirable and this is the reason for bringing into life the project CRIMP (Criteria for the Evaluation of Audiovisuals in Multimedia Productions) in 2001. It's aim was to bridge the gap between multimedia and hypermedia research by

- testing single modules of different instructional design while
- embedding them in a complex learner-controlled hypermedia environment
- in a realistic classroom setting.

Design of the project CRIMP (for further details see the following methods chapter)

The project CRIMP pursued an experimental approach to answer questions on the effectiveness and efficiency of learning with hypermedia systems. By using four different evaluation variants of a software on cell biology, i.e. the presentation of content in varying complexity, CRIMP studied the navigation patterns and learning performance of students, while also taking learner characteristics into account. Tests were performed in realistic learning scenarios at schools and colleges with about 700 students in Germany (e.g. Huk et al. 2002; Huk et al. 2003a; Steinke et al. 2003a/b).

The crucial question CRIMP tried to answer was the following: How does the instructional design of content modules in hypermedia learning environments influence the motivation, the focus of attention, the learning process and the learning success of the users?

The test setting limited the external impact factors so that differences in the learning process and outcome could be correlated with the software design.

The software variants

To investigate the impact of audiovisual pictorial information on learning four variants of a software on cell biology were developed offering different didactical and graphical design but the same content. Specifically, two modules of the software were modified with respect to certain content design parameters:

- a module focusing on the structure and function of plant and animal cells – the latter was used to study the impact of 3D-models, close-up-views and 3D/2D-static picture design;
- a module explaining the structure and function of the ATP synthase – the latter was used to investigate the impact of animation design specifically 3D/2D-design and the presence/absence of signals.

Data collection and analysis

As highlighted above, the data collection was carried out at schools and universities directly, each test series consisting of three consecutive working sessions.

In order to ensure that later on the test results could be interpreted taking the learner characteristics into account in the first session computer literacy, prior domain knowledge, learning style and spatial ability were assessed with a number of questionnaires.
In the second session students were asked to use the four software variants on cell biology. Each student or student group worked with one version of the evaluation software. The individual's/group's navigation processes got documented with encoded log files. Following the work with the software the students` learning performance was tested with questionnaires on the software's topic, i.e. cell biology. Furthermore, students were asked to evaluate the software.
In the third session the long-term learning outcome was assessed with questionnaires.

Subsequently, for further analysis of the dissertation theme (see below), the log files were decoded and got analyzed with a variety of methods including a principal component analysis. The resulting main usage factors could then be correlated with the different variants of the CD-ROM as well as with individual learner characteristics.
The learning outcome was assessed by the analysis of the questionnaires on cell biology, the latter being presented elsewere (see e.g. Huk & Steinke 2007; Huk et al. in press).

1.5.2 The dissertation

As outlined earlier, the cognitive load theory builds an accepted theoretical framework for research on instructional design and its implications. However, the moderating role of user activities in learner-controlled hypermedia systems and the impact of content design features on those activities yet needs to be taken into consideration. In this context Gerjets & Scheiter (2003) suggest an extension of the cognitive load theory (see section 1.1 and figure 1) by considering the software usage of learners and the impact factors on the latter as a moderator between instructional design and learning outcome (Gerjets & Hesse 2004; Gerjets & Scheiter 2003).
One basis for an evaluation of the effectiveness and efficiency of learning with multimedia materials is to know how users navigate through hypermedia systems with different instructional design and by doing so how they gain knowledge. Research on instructional design features so far has however often focused either on the level of the system or the content design of a single module. Moreover, not much is known about the impact of instructional design properties on learning processes in hypermedia environments. Specifically, the influence of content modules that contain animated pictorial information on

the navigation process so far has not been investigated intensively. Research on films and animations e.g. very often is considered to be limited by the fact that most of the educational audiovisuals are shown solitarily and not integrated in learner-controlled hypermedia environments.

The questions arising can therefore be summarized as such: What factors exhibit an impact on software use and navigation? Is software use influenced by content design? Does a variation of the design lead to different usability, i.e. different navigation patterns and learning outcome? Do design effects remain when multimedia is used under learner-controlled circumstances, i.e. are results transferable from the testing of the design effects of solitary modules to the use of these modules within learner-controlled hypermedia environments?

Do learner characteristics influence the software use? Can software use predict learning outcome?

Against this background the impact of software design and individual differences on the learning process in instructional hypermedia environments constitute the focus of the dissertation presented. In doing so it tries to follow a more integrated approach which means that learner characteristics as well as the content design are considered to have an impact on the usage behavior - on the level of the system (navigation and learning support features) as well as on the level of the content itself. A review of literature as well as the results of different pre-tests in context of this project led to the formulation of the following three hypotheses:

If students use a complex hypermedia environment, each of the following content design features such as

- *presence/absence of 3D-models,*
- *presence/absence of close-up-views,*
- *3D/2D-design of a static picture,*
- *3D/2D-design of an animation,*
- *and presence/absence of signals in an animation*

will have a significant impact on the use of the content as well as on navigation and the use of learning support tools (e.g. a glossary)!

The first hypothesis was investigated with students learning individually.

As outlined above, collaborative learning may add cognitive load to learning. Against this background the impact of software design features on the learning process of students working in groups was investigated. For software equipment at schools is frequently limited the latter may represent the most realistic learning scenario anyway. This leads to the second hypothesis:

If students learn in small groups (dyads) while using a complex hypermedia environment the impact of the design of audiovisual content on the software use will be different to the impact on students learning solitarily!

Moreover an investigation on the impact of learner characteristics, i.e. prior domain knowledge, spatial ability and learning style, on hypermedia use was carried out. Due to the great variety of variables investigated in this study, the analysis did not take interaction effects between individual differences and software design nor aspects such as computer literacy into account but focussed with a third hypothesis on the general impacts of three important learner characteristics on software use:

If students use a complex hypermedia environment, the learner characteristics prior domain knowledge, spatial ability and learning style will each have an impact on the use of the content as well as on navigation and the use of learning support tools!

Logfile tracking was chosen to record the users' navigation through the hypermedia environment. The subsequent analysis of the latter revealed a more accurate picture of the learning process. Naturally, the prerequisite for the findings' correct interpretation represented their linkage with the information on the users' characteristics such as domain specific knowledge, learning style and spatial ability. The study's results thereby contribute to the body of evidence to facilitate the development of design guidelines on how to produce or select instructional multimedia and hypermedia material that optimally complements users' needs.

2 Methods

The use of hypermedia in natural sciences seems to represent a relevant area for research as the multi-medial illustration of selected crucial phenomena taking place on the nano-/micro-level may significantly enhance the learners' understanding of these complex processes. In light of the above the research team, natural scientists themselves, decided to work with a commercially available hypermedia learning environment on cell biology. As described in detail in the previous chapter, the dissertation presented focuses on the interplay of the individual learner's characteristics as well as the software design and the knowledge acquisition process, i.e. the analysis of the log files. All aspects related to the analysis of the learning outcome, i.e. the analysis of the post software use knowledge questionnaires on cell biology are described and published elsewere (see e.g. Huk & Steinke 2007; Huk et al. in press). However, for the sake of the readers´ understanding of the research project and for the fact that the dissertation's results are among others naturally also interpreted in light of the findings on learning outcome, the following chapter provides an overview on the methodology of the CRIMP project as a whole:

a) To investigate the impact of content design, specifically the didactical and graphical, on the software use, the software was manipulated in two sections creating a number of variants of the same content but differences in the design's sophistication.

b) Subsequently, a large number of experimentees, students of biology at grammar school and college level, were asked

   i) to complete a number of pre-tests ascertaining the users' learner characteristics such as visual spatial ability, learning style and prior domain knowledge;

   ii) to study - in accordance to the specific trial's objective (either individually or in dyads) – a number of different topics in cell biology each working with one of the software variants (the latter being allocated at random), while the experimentees' navigation through the software was tracked with log-files documenting the number of clicks and amount of time on pages.

c) After the study session with the software the students' learning outcome was assessed in two consecutive tests and the students were asked to evaluate the software.

d) Analyzing the data collected, i.e. relating the information contained in the pre- and post-tests as well as the log-files, the various factors' interplay as well as their impact on the knowledge acquisition process was assessed.

The software and all questionnaires exist in German and English language versions. As the study presented was carried out at German schools and universities naturally the German language versions of all instruments were used and the English language versions piloted in bilingual classes. In order to support non-German speaking readers the English versions of CD narration as well as the pre- and post-test questionnaires (as presented in the methods chapter as well as the annexes) are presented.

In the following, the methodology will be described in detail.

2.1 The experimentees

Over 700 individuals, students of 18 different grammar schools (34 classes) of 5 German *Bundeslaender*, i.e. Baden-Wuerttemberg, Hamburg, Lower Saxony, North-Rhine-Westphalia, Schleswig-Holstein, as well as of 3 universities in Baden-Wuerttemberg (Karlsruhe) and Lower Saxony (Braunschweig and Goettingen) took part in the investigation. For a complete list of all schools, universities and the respective classes involved see the annex section. In accordance with the target age group of the commercially available CD-Rom only biology school classes of the grades 11 to 13 and university students at undergraduate level were admitted for testing, the mean age of the experimentees' being 18.2 years. This approach was chosen in order to guarantee the adequate motivation to tackle the tasks at hand among the examinees: the topic of the hypermedia learning environment to be tested, i.e. the software on cell biology, required some familiarity with the subject area; at the same time a prerequisite for successful testing was the assumption that the experimentees would at best have limited prior knowledge on the specific topics to be studied in the test session.

The acquisition of experimentees at the onset of the project was pursued with the project team attending workshops, educational fairs and conferences to present and promote the study. In light of the above schools and universities were chosen randomly.

2.2 The setting for testing

All testing was performed on the premises of the participating schools and universities, i.e. the test sessions were taking place in the class rooms of the biology courses involved, with the project team as well as the respective classes' biology teachers/ lecturers being present. The material for testing, i.e. the pre- and post-test questionnaires as well as the hard- and software (for details see below), were brought along and installed by the project team prior to the test sessions.

As outlined in the introduction chapter literature reports of a huge number of experiments under highly controlled conditions. This of course has positive implications for the internal validity and enhances the postulation of any chain of cause and effect but impedes on the generalization of results and their significance in realistic settings, i.e. the experiment's external validity (Brosius & Koschel 2001). Against this background the project team conducted pre-tests in controlled settings: students were asked to study one of the research project's software topics, i.e. ATP synthase, by watching a movie with no choice provided to interact with the hypermedia environment. The comparison of results with those arrived from tests in more realistic settings (i.e. the class room with students being asked to work freely with the software) suggested that the investigated factors impacting on the knowledge acquisition process were operating to the same effect in both settings. Conscious of the problems associated with the additional potential confounding factors present in a natural setting, the project group decided to aim for a testing situation close to the instructional reality in schools and universities, i.e. the class room setting, to enhance the study's external validity.

2.3 The testing material

As mentioned above, during the test sessions a number of different instruments were used (for details consult below the section on how the experiment was carried out as well as the annex section) -

a) a standardized introduction to the project and the request to sign a declaration of consent regarding the further use and processing of the experimentees' data;

b) a number of pre-test questionnaires to ascertain the experimentees' learner characteristics, including visual spatial ability, learning style and prior domain knowledge;

c) 4 variants of a CD-Rom on cell biology in the test session to investigate how students learned with a complex hypermedia environment, i.e. what factors impacted on the process of learning; to this end a log file-tracking functionality had been integrated in the software variants;

d) a number of post-test questionnaires to evaluate the learning outcome as well as the students' evaluation of the software.

The instruments are described in the following. All questionnaires were used in hard copy only.

2.3.1 Pre-test questionnaires on learner characteristics

The pre-test questionnaires on learner characteristics included tests on visual spatial ability, prior domain knowledge and learning style. They are described in further detail in the following sub-chapters.

2.3.1.1 Prior domain knowledge

A number of studies have shown the impact of prior domain knowledge on individual learning (Huk et al. 2004; Huk et al. 2003c; Kalyuga et al. 2003; Mayer 2001) and postulate that the prior domain knowledge constitutes an important determinant of hypermedia navigation (e.g. Lawless & Kulikowich 1998). Against this background a questionnaire on prior domain knowledge, in this case regarding cell biology, specifically the crucial processes the bio-molecule ATP is involved in as well as the differences of animal and plant cells, was developed by the project team in close cooperation with biology teachers and lecturers. The latter acknowledged the relevance of the topics for the tests' target group while confirming that the details on the topics to be learned were not likely to be known to the target group. The questionnaire was piloted with 100 students and subsequently revised. It consists of open as well as multiple choice questions. For more details see the annex section.

2.3.1.2 Visual spatial ability

Many authors, e.g. Hays (1996), stress the necessity of investigations focusing on the influence of visual spatial ability when learning with computer-based animations. Moreover, some authors postulate that tests to measure field-dependence/independence (e.g. GEFT) seem to reflect primarily spatial-visual abilities as indicators of an individual cognitive style; i.e. the spatial-visual ability is considered an important characteristic of information processing.

One of the study's foci laid on assessing the impact of graphical complexity of the software on learning; in light of the above the 3-dimensional visual perception of the participating students was therefore assessed with the tube figures test, the "Schlauchfiguren-Test" (Stumpf & Fay 1983) during the pre-test session. Validation studies have shown that the instrument which is well known in Germany calls for both spatial ability and deductive reasoning (Reiss et al. 2000). In the tube figures test, different angles of complex tubular figures have to be judged: students are presented different sets of pictures each featuring a glass cube (without spatial cues of the dimension of the cube) containing a winding flexible tube. In each set of pictures, the left pictures show the forefront of the cube while the right picture portraits the cube from a different angle. Students have to decide what side of the cube is depicted in the right picture, i.e. right/left/bottom/top/back. The test features 21 different sets of pictures. The test's supply source is provided in the annex section.

2.3.1.3 Learning style

To measure the individual learning style of the participants the *Index of Learning Style* (B. A. Soloman and R. M. Felder (http://www.ncsu.edu/felder-public/ILSpage.html)) was used. As outlined in the introductory section the method is based on a learning style model with dimensions considered particularly relevant to science education (e.g. Zywno 2003; Felder 1993). The model describes four learning dimensions, i.e. active (act) / reflective (ref), sensing (sen) / intuitive (int), visual (vis) / verbal (ver) and sequential (seq) / global (glo). It is postulated that the dimensions exist more or less well-balanced in all learners. Only individuals with a pronounced preference for one dimension may face difficulties learning in a learning environment which does not support that preference. In the present project the test's reliability (for details see below) was assessed for all participants and only students with a pronounced preference for one dimension were included in further analysis. The test was chosen in close cooperation with the evaluation board for research methodology of the research institution hosting the CRIMP project, the L3S Research Center. The questionnaire is based on the Likert technique, also called the "method of summed ratings", which uses rating-scales for self-estimation. The questionnaire for assessing the preferences on the four dimensions of the learning style model as well as the scoring sheet which helps interpret the individual's scores is enclosed in the annex section.

2.3.2 The post-test questionnaires

The post-test questionnaires included knowledge tests on both tasks (structure and function of the cell / ATP synthase) and a questionnaire to evaluate the software. As the results on learning outcome as well as the software evaluation are presented elsewere, here the questionnaires are not outlined in any further detail.

2.3.3 The hardware

Depending on the research question to be answered in the respective software testing session, students were either working with one computer each, then with no interaction with fellow students, or working in groups of two students per computer. In order not to create additional confounding factors by working in the different schools with different sets of PCs and to take account of the infrastructural inter-school/ -university differences altogether, all testing was performed with the same batch of 25 iMacs, model G3 400 with 15-inch screens. Thanks to the generous project support of the institute IWF Knowledge and Media in Goettingen, Germany, the latter could be rented for a symbolic fee for the duration of the testing period. This approach included the project team transporting the batch of iMacs from one to the next of the participating schools and universities and installing them in the class rooms prior to the respective testing sessions. In classes with 25+ students the project team used additional laptops.

Prior to the testing sessions in schools and universities the project team ensured that the software variants (see below) were installed on the different iMacs. The log-pad-programme on the iMacs' local drives enabled the log files to be recorded (for details see below).

As narration was one of many different hypermedia features of the test software, all students were also provided with head sets in order to ensure undisturbed working of the individual.

2.3.4 The software

As mentioned above, at the core of the investigation stood the question how instructional software should be designed to support learning effectively and efficiently. Against this background the research team chose a study set up to ensure best possible external validity: the test sessions not only took place in a realistic class room setting but also a hypermedia software was used with the modules to be tested embedded in a complex hypermedia environment. Different studies suggest that the integration of sophisticated features such as 3D-animations and videos in principle exhibit a stronger pedagogical potential than static pictures (e.g. Craig et al. 2002). However, the development and integration of computer animations has to be evaluated among others in light of their financial implications as the latter constitute a big proportion of the total cost for producing hypermedia. Against this background the project team produced different evaluation versions of a CD-Rom on cell biology exhibiting different design features to study navigation patterns and learning performance of students.

Accordingly, the four evaluation variants produced were technically altered with:

a) a log-file tracking functionality including an encoding function being added to all versions;

b) the content remaining unchanged but the instructional design, i.e. didactical and graphical elements, getting altered in two topic areas, i.e.

    i) the section describing the features inherent to animal and plant cells, and

    ii) the section dealing with the bio-molecule ATP (for details see below).

The programming of the variants was undertaken by the company MMCD, Duesseldorf. A debugging step was introduced to refine the variants and ensure their proper functioning. The variants produced and burned on CD-Rom represent hybrid versions installable on PCs as well as Macs.

As mentioned above, all variants had been programmed to contain a log-file-tracking functionality recording the screens visited, their sequence as well as the time spent on each. The company MMCD provided the project team with the information on how to decode the log file entry, i.e. to identify the screens that were actually studied as well as the navigation through the software, i.e. the buttons clicked, etc.

In the following the hypermedia environment in general as well as the specific features of the variants produced are described in further detail.

2.3.4.1 The hypermedia learning environment: general features of the software

The award-winning software "The Cell II – The Power Plant – Mitochondrium and Energy Metabolism" provided the basis of the study presented. The software that had been developed by the institute IWF Knowledge and Media, Goettingen, Germany, is available in the languages English and German and provides a large quantity of information on cell biology while offering an array of navigation possibilities. Furthermore, the software offers a broad range of media such as movies, animations, Quicktime VRs and other features calling for interactive exploration.

Introduction and start screen

The software's entry screen offers a film providing an introduction to the topic. Thereafter the start screen (figure 4) opens up that offers three possibilities for further navigation:

a) an explorative tour

b) two guided tours dealing with "function of mitochondria" and "structure and reproduction", or

c) a sitemap, also called compass.

Figure 4 Screen shot of the CD-Rom' s start screen

Explorative tour

When clicking on the button "explorative tour" a three-dimensional model of an animal cell is shown (see figure 5). Via buttons in the upper left and right corner of the model the user can change directely between models of a plant and animal cell respectively. As this content module was modified for one of the experiments of this study it is described in further detail in sub-chapter 2.3.4.2. The 3D-model is the starting point for the user from which he or she can begin to explore the different sections of the software.

Figure 5 Screen shot of a 3D-model of the animal cell

Guided tours

Starting one of the guided tours "function of mitochondria" or "structure and reproduction" leads to a content screen that allows to continue a fixed tour with the buttons "next step" or "one step back" (see figure 6 – screenshot of the guided tour "structure and reproduction"). At the end of each tour the user is offered the choice to return to the start screen. It is also possible to get back to the start screen clicking the button "one step back" or the button "quit tour".

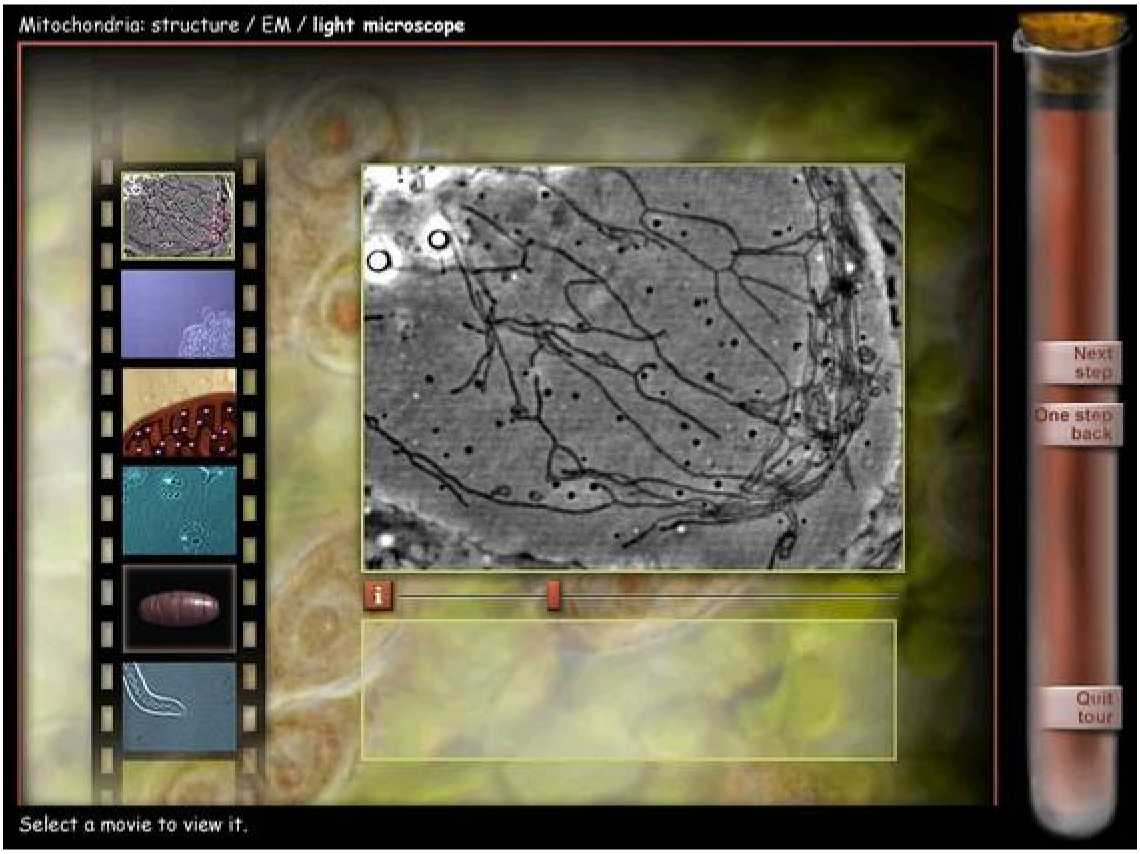

Figure 6 Screen shot of the guided tour "structure and reproduction" (with restricted navigation possibilities)

Sitemap

Clicking on the button “compass” opens up the central sitemap which allows direct access to the majority of the content modules of the software. Figure 7 shows a screenshot of the sitemap. At the bottom of the sitemap there are several buttons that enable the user to view a collection of films (button “all movies”), animations and 3D-models (button “3D-lab”), to choose a quiz with about a hundred questions, to use a print function or to quit the programme. With the buttons situated in the top part of the sitemap it is possible to navigate back to the introduction (button “intro”) or to the start screen (button “tours”). The buttons “animal and plant cell” lead to the 3D-models of an animal or plant cell respectively. The screen with the model of the animal cell is identical to the one opening up when clicking on the button “explorative tour” on the start screen.

Figure 7 Screen shot of the CD-Rom’s sitemap (compass)

Test tube

The test tube on the right side of the screen features in all screens, and is shown in more detail in figure 8. Except for the guided tours which offer restricted navigation possibilities only (see figure 6), the test tube represents together with the sitemap one of the main navigation instruments of the software. The front view of the test tube (figure 8, left) offers a hierarchical menu, the sitemap, an alphabetical index, a glossary, a notepad, links to content-related pages providing further details on the respective topic as well as two buttons with an arrow up (upper hierarchy level) and an arrow to the left (one screen back). Additionally, the sound volume can be modified here. Clicking on the arrow at the top of the test tube allows the user to turn the test tube: then the buttons that also feature at the bottom of the sitemap appear – for details see figure 8, with the print function, the possibility to choose all films of the CD (button "cinema"), all animations and 3D-models (button "3D-lab"), the quiz, and a button to quit the programme. Additonally, a help function is offered.

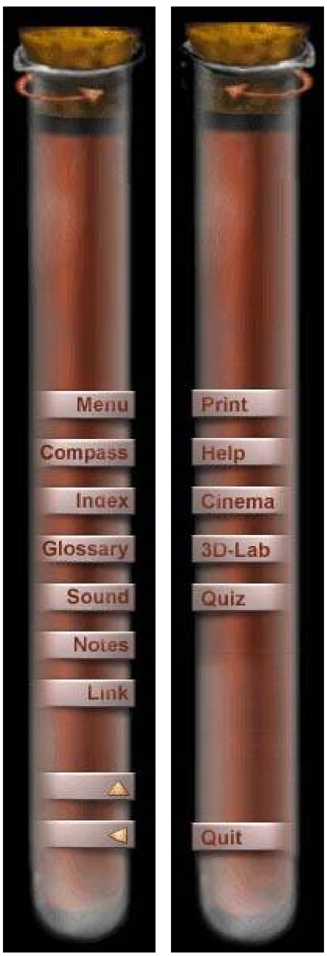

Figure 8 Screen shot of the software's navigation feature "test tube" (left picture: front view, right picture: back view)

The test tube has the same appearance on all screens with exception to the front view of the screens of the plant and animal cell. Here an additional questionmark is positioned above the other buttons which provides some information on the different buttons of the test tube.

In the following the different screens and features that can be activated by the buttons positioned on the test tube or the sitemap are described in further detail.

Menu

The button "menu" takes the user to the main menu of the central topic of the software - mitochondrium and energy metabolism. From here the user can continue with the function structure or reproduction of mitochondria. Figure 9 shows the screen with the main menu.

Figure 9 Screen shot of the software's main menu feature

Index

On the index screen an alphabetical index is shown. It is possible to click directely on an index term to get to the selected screen.

Glossary

On this screen the user is provided with short definitions of important terms that feature in the different content modules of the software. They can be chosen alphabetically (see figure 10).

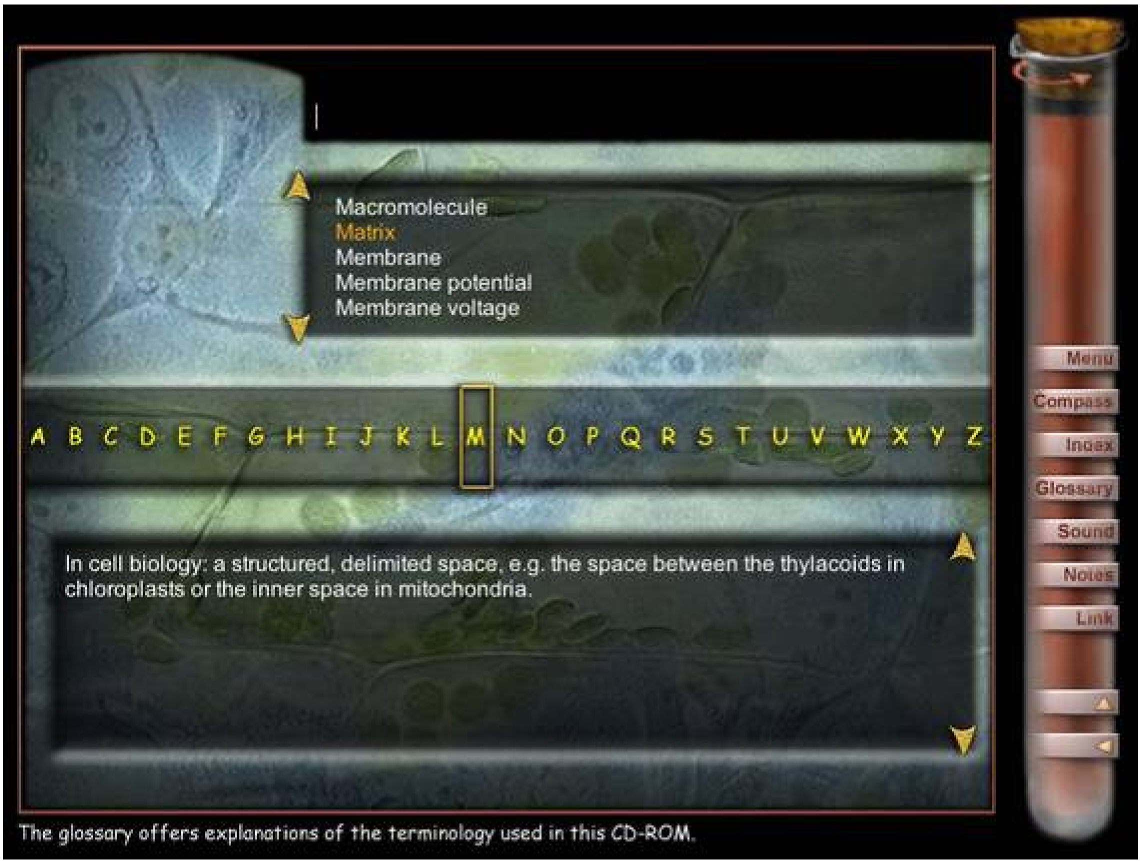

Figure 10 Screen shot of the software's glossary feature

Notes

By a click on this button a notepad opens up. After filling in the notes it can be saved and used in further sessions.

Links

A click on the button "link" opens a small window listing content-related topics that can be selected by the user. The links thematically closest to the actually opened screen are positioned on top of the list.

Arrows "up" and to the left side

These arrows lead the user either to a screen one level further up in the hierarchy (arrow up) or back to the previous page (arrow to the left side).

Cinema / all movies

A click on the button "cinema" on the back side of the test tube or on the button "all movies" of the screen sitemap opens up the collection of all film sequences that are used in the different content modules of the software. They can be watched directly from this screen. Upon the first opening of the screen an empty movie player and a list of films (small screen shots, see figure 11) is shown. The film is started according to the user's selection.

Figure 11 Screen shot of the cinema/all movies function of the software

3D-lab

A click on the button "3D-lab" on the back side of the test tube or the sitemap displays the collection of all interactive 3D-models that are used in the different content modules of the software. The single 3D-models can be selected in the same manner as the film segments on the cinema screen can be chosen (see above).

Quiz and quiz videos

The quiz is designed to help the user evaluate the acquired knowledge: clicking on the button "quiz" on the back side of the test tube or of the sitemap a screen opens up which offers different sets of questions or quiz videos on specific topics.

After choosing a specific set of questions the individual questions are generated automatically and can be answered choosing from a multiple choice format. Visual and auditive feedback is provided for a correct or wrong answer. An example for a correctly answered question is featured in figure 12.

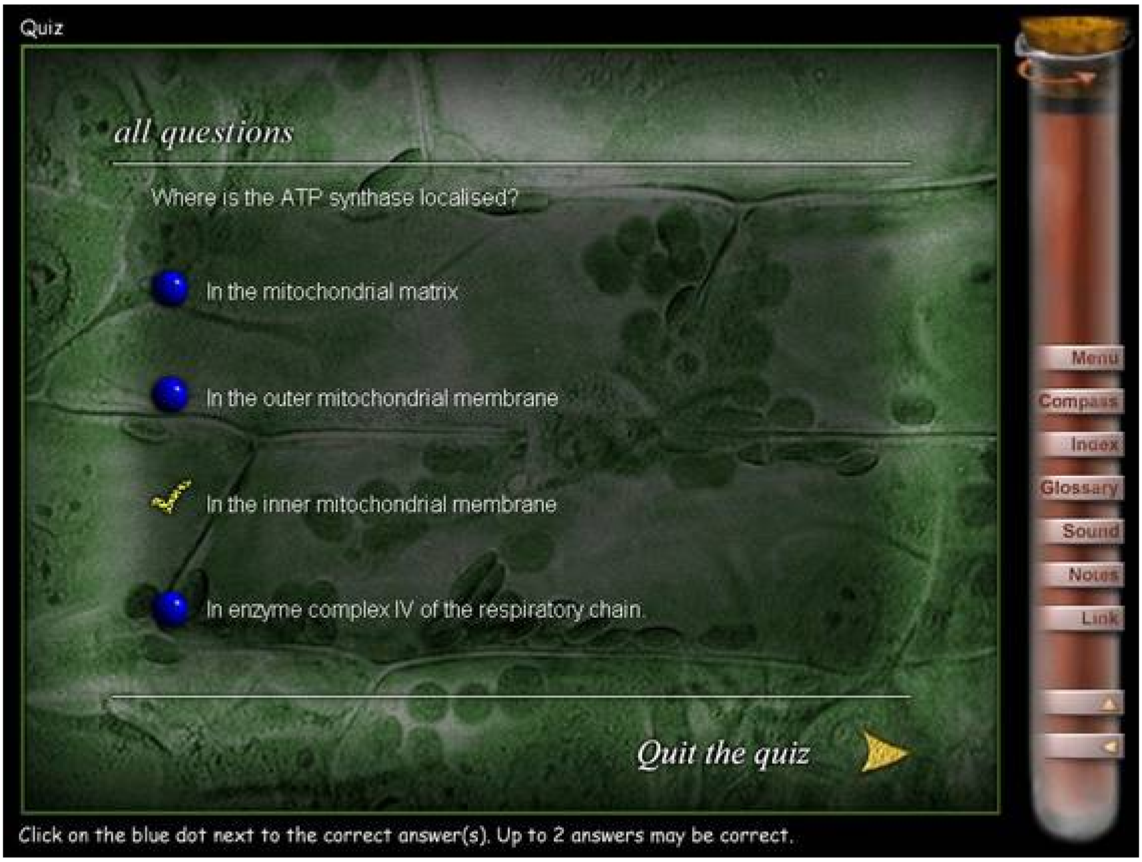

Figure 12 Screen shot of the software's quiz function I (a question and its correct answer)

When users choose quiz videos they get a selection of interactive flights through plant or animal cells, a mitochondrion or a chloroplast respectively. When the term of an organelle or specific structure is shown below the movie player the user has to click on the respective organelle or structure in the interactive video (figure 13). The flight is repeated until the user has identified all structures or organelles correctly.

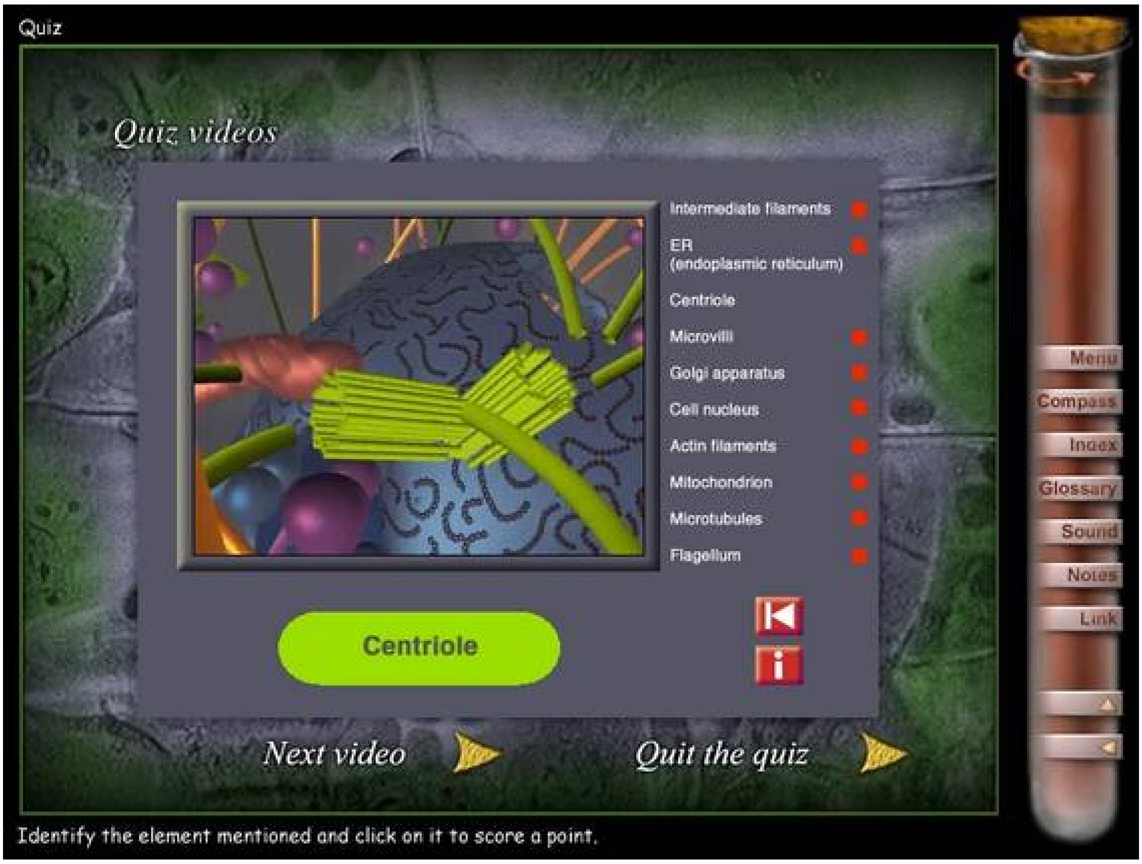

Figure 13 Screen shot of the software's quiz function II: quiz video (demanding a click on the centriole of the animal cell)

Help function

The help function provides definitions and explanations for the respective screen chosen by the user. Moreover, the availability of forward and back buttons enable the user to move from one to the next or previous explanation.

2.3.4.2 The four variants of the software

In light of the general trend to invest in costly 3D-features and animations while few studies are available confirming their beneficial effect on learning, specifically two sections of the software were manipulated to produce four variants offering the same content with different design features. By doing so it was aimed to evaluate the impact of visual content representation on navigational behaviour, the knowledge aquisition process and the learning outcome.

The questions to be answered were the following:

1) Do additional 3D-features, without the provision of additional information, impact positively on the user's motivation, thereby effecting navigational behaviour and subsequently learning outcome?
2) Do close-up-views improve understanding, thereby effecting navigational behaviour and subsequently learning outcome?
3) Does the graphical design of static pictures (3D vs. 2D) influence the users' motivation and understanding, the knowledge acquisition process and subsequently learning outcome?

Furthermore, the graphical quality of animations (3D versus 2D) as well as the didactical value of using signals or cues, the latter motivated by previous studies' contrasting results (see Craig et al 2002; Mautone & Mayer 2001), were investigated.

2.3.4.2.1 Module "plant- and animal cell" – the impact of 3D-models, close-up-views and static picture design

The commercially available software version of the module "animal and plant cell" includes a number of sophisticated graphical features such as Apple Quicktime VR, a track-based file format in which each track delivers different content elements (audio, video, HTML, interactive elements) (Apple 2001) letting the user examine and explore photorealistic, three-dimensional virtual worlds. The VR-movies are completely interactive and allow navigation within an object, zooming as well as linkage of different movies. Furthermore, the module includes the animation "flight through the cell", close-up-views and 3D-cross sections to explain the complex phenomena taking place at cell level. Accordingly, the most complex evaluation variant produced includes freely movable models of animal and plant cells respectively as well as a cross section through the cell with a three-dimensional look and feel. Moreover, oral explanations are provided. The other three versions present the same content with the same oral comments in a gradually less sophisticated graphical design: two differ in the existence / non-existence of close-up-views accompanying the narration. The simplest version consists of a cross section through the cell designed in a two-dimensional look and feel.

The contrast between version 1 and 2 was intended to answer question 1 as outlined in the introduction of the section 2.3.4.2. The a priori-contrast between versions 2 and 3 was intended to answer question 2, while the contrast between versions 3 and 4 finally was designed to answer question 3.

The variants were designed to support a subsequent one factor (monovariate) analysis of variance/ the one factor generalized linear model (GLM) with one factor varying in 4 degrees and representing the graphical sophistication of the content visualization. The differences between the four variants are summarized in table 1; subsequently the 4 variants are presented in further detail.

Table 1 Cell: differences among the four software variants

	QuicktimeVR-model	animation „flight through the cell“	narration with close-up-views being present*	graphical sophistication of cross section
version 1	yes	yes	yes	3D
version 2	no	no	yes	3D
version 3	no	no	no	3D
version 4	no	no	no	2D

*As mentioned above, the narration did not differ among the 4 versions.

In table 2 the module’s narration is presented.

Table 2 The narration accompanying the module "animal and plant cell"

Placement in module	narration
start of screen "plant cell"	This is an idealized plant cell. The outer layer, the cell wall, has been removed.
start of screen "animal cell"	As an example for an animal cell an epithelial cell was selected here. Typical for this cell form are the small protuberances on the cell surface, the microvilli. Some cells may develop a flagellum.
plant-/animal cell: technical term "nucleus"	The nucleus contains most of the genetic complement of a cell. This genetic information is passed on to the daughter cells during mitosis and cell division. In the interphase the nucleus regulates the synthesis processes of the cell.
plant-/animal cell: technical term "endoplasmic reticulum"	The endoplasmic reticulum consists of a complex branching network of cisterns. Its function is the synthesis of proteins and lipids. If the cytoplasmic surface of the cisterns is densely covered with ribosomes it is referred to as rough endoplasmic reticulum.
plant-/animal cell: technical term "dictyosome"	The golgi apparatus consists of stacks of flat membranous sacks. The golgi apparatus serves to prepare and package substances for export to the cell membrane or to the lysosomes.
plant-/animal cell: technical term "mitochondrion"	Mitochondria are the organelles associated with cellular respiration. Their inner membrane is strongly folded inwards and contains the enzyme complexes for the respiratory chain and oxidative phosphorylation.
animal cell: technical term "centrioles"	Centrioles are the microtubuli-organizing centres of the cell. They can form the basal bodies of cilia and play a major role in nuclear division.
animal cell: technical term "microvilli"	Microvilli are evaginations of the cell membrane. They are typical for the absorptive epithelia and serve to increase the surface area. In their totality, they are also designated as the brush border.
animal cell: technical term "intermediate filaments"	Intermediate filaments serve to increase the mechanical strength. There are many variants of them. Their diameter is approximately 10 nm.
animal cell: technical term "microtubules"	Microtubules form the central elements of cilia and flagella. With a diameter of 22-25 nm, they are the largest structures of the cytoskeleton.
animal cell: technical term "cilium"	Cilia are elements of the cytoskeleton. Around two central microtubules, nine additional tubule pairs are arranged in a circle. They are shielded by the cell membrane.

Table 2 The narration accompanying the module "animal and plant cell"

Placement in module	narration
plant cell: technical term "chloroplast"	Chloroplasts are the cellular organelles of photosynthesis. They only occur in plant cells and contain the pigments which absorb solar energy and transform it into biochemical energy. The green colouration of many plant organs is due to the presence of chlorophylls.
plant cell: technical term "cytoplasmic strands/ vacuole"	The vacuole is a characteristic feature of the plant cell. It occupies most of the interior of the cell and displaces the organelles into a thin peripheral plasma layer. Many cytoplasmic strands pass through its interior.
plant cell: technical term "microtubules & actin filaments"	In plant cells, the microtubules, represented in yellow here, and actin filaments, here red, effect the arrangement of the organelles and their movement within the cell.
plant cell: technical term "plasmodesma/ cell-cell-junction"	Plasmodesmata form connections between adjacent cells. They consist of thin cytoplasmic connections and are frequently pervaded by tubular extensions of the endoplasmic reticulum.

CD version 1 – the variant with the most sophisticated graphical content visualization

Version 1, the variant with the most sophisticated graphical content visualization is identical with the commercially available software. This variant presents the features of plant and animal cells on three screens respectively. In the following the variant will be described in further detail illustrating the specific features with exemplary screen shots of the plant cell pages.

On the first screen a 3D-computer model of an animal and plant cell with its cell organelles is presented (figure 14 shows a plant cell). The model is said to present one of the best models and closest to reality currently available. On first entry, the screen shows a static picture of the 3D-cell model and an oral commentary explains the screen's content. Subsequently the static picture is replaced by a model containing Quicktime VR features which enable interactive exploration of the model, e.g. zooming in and out on the cell and its organelles while no further oral explanations are provided.

Figure 14 Screen shot of CD variant 1: Entry screen "plant cell" featuring the interactive VR-model

On the second page a linear animation of the same 3D-cell model allows the virtual flight through the animal and plant cell respectively. The animation starts off with a view on the cell as a whole with the option to subsequently zoom into the 3D-model (figure 15) featuring the different cell organelles while no narration is provided.

Figure 15 Screen shot of CD variant 1: The plant cell's page featuring the animation flight through the cell

The third page finally provides a 3D-static cross section of the animal and plant cell respectively (fig. 16); the cross section is framed by the names of the single cell organelles.

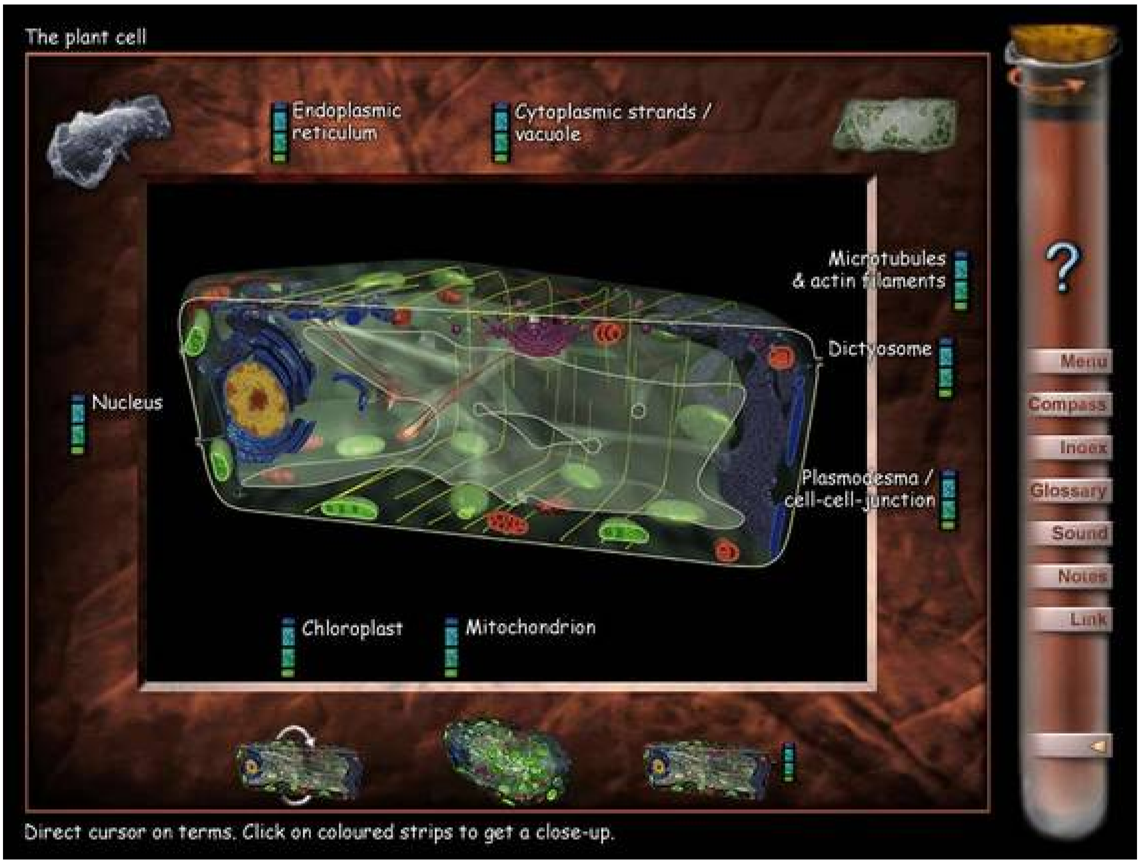

Figure 16 Screen shot of CD variant 1: The plant cell's third page featuring a cross section of the cell incl. cell components and technical terms. Below the cross section small buttons featuring the pages 1 and 2, i.e. the 3D-Quicktime VR model of the cell and the animation cell flight, allow easy navigation between the screens.

In case the cursor is rolled over one of the terms framing the graphic the respective cell component is highlighted and a connecting line between the component and its technical term shows up (figure 17 illustrates the roll over feature with the term Nucleus).

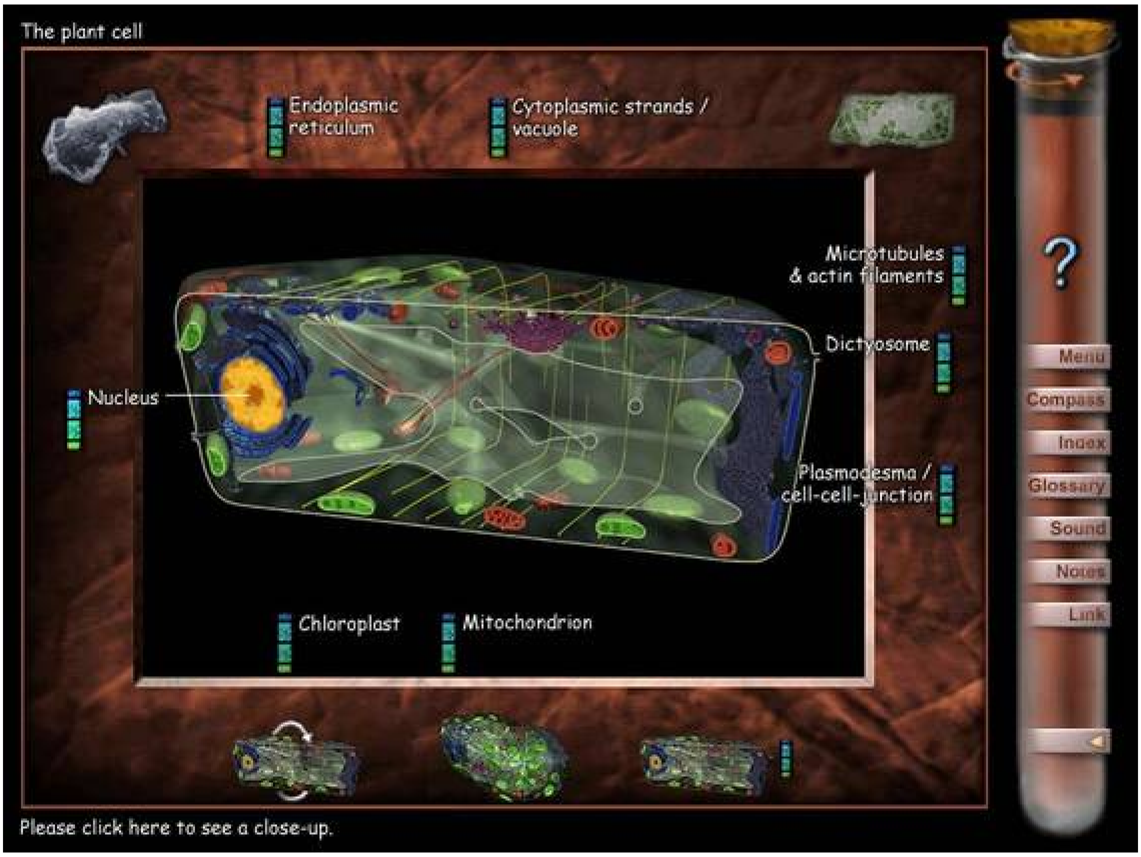

Figure 17 Screen shot of CD variant 1: The plant cell's third page featuring a cross section of the cell – illustration of the roll over feature showing the connection cell component and term "nucleus".

A click on the term subsequently opens a close-up-view of the respective cell component while an oral explanation regarding the component's function is started (figure 18).

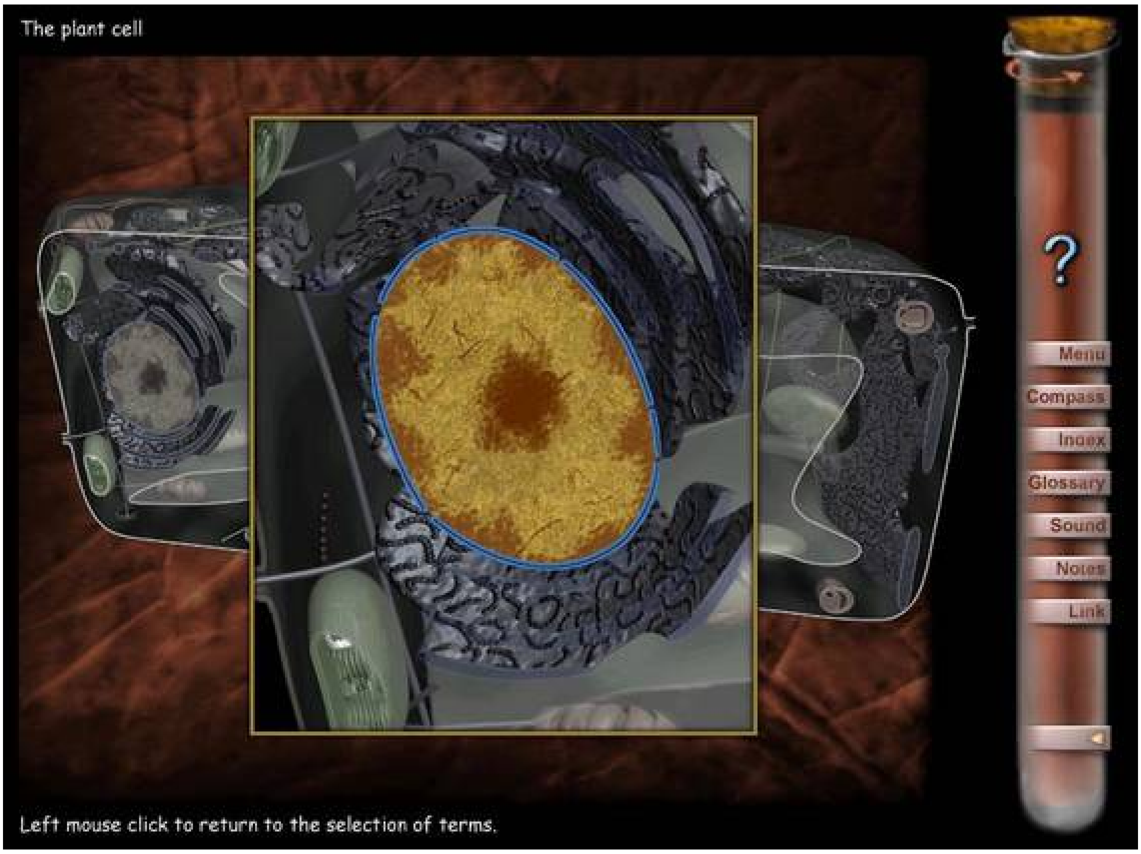

Figure 18 Screen shot of CD variant 1: The plant cell's third page featuring a cross section of the cell – illustration of the close-up-view of a single cell component after clicking on the term "nucleus" while narration is provided.

CD version 2 – absence of interactive 3D-models

In version 2 the sophistication of the graphical visualization was reduced by taking out the interactive QuicktimeVR model as well as the animation “flight through the cell”. Against this background variant 2 consists of one page only, i.e. the page featuring the cross section of the plant and animal cell respectively (obviously without the navigation buttons referring to the pages (figure 19). The features roll over, highlighting and close-up- views function in the same way as in version 1 (see figures 17 and 18).

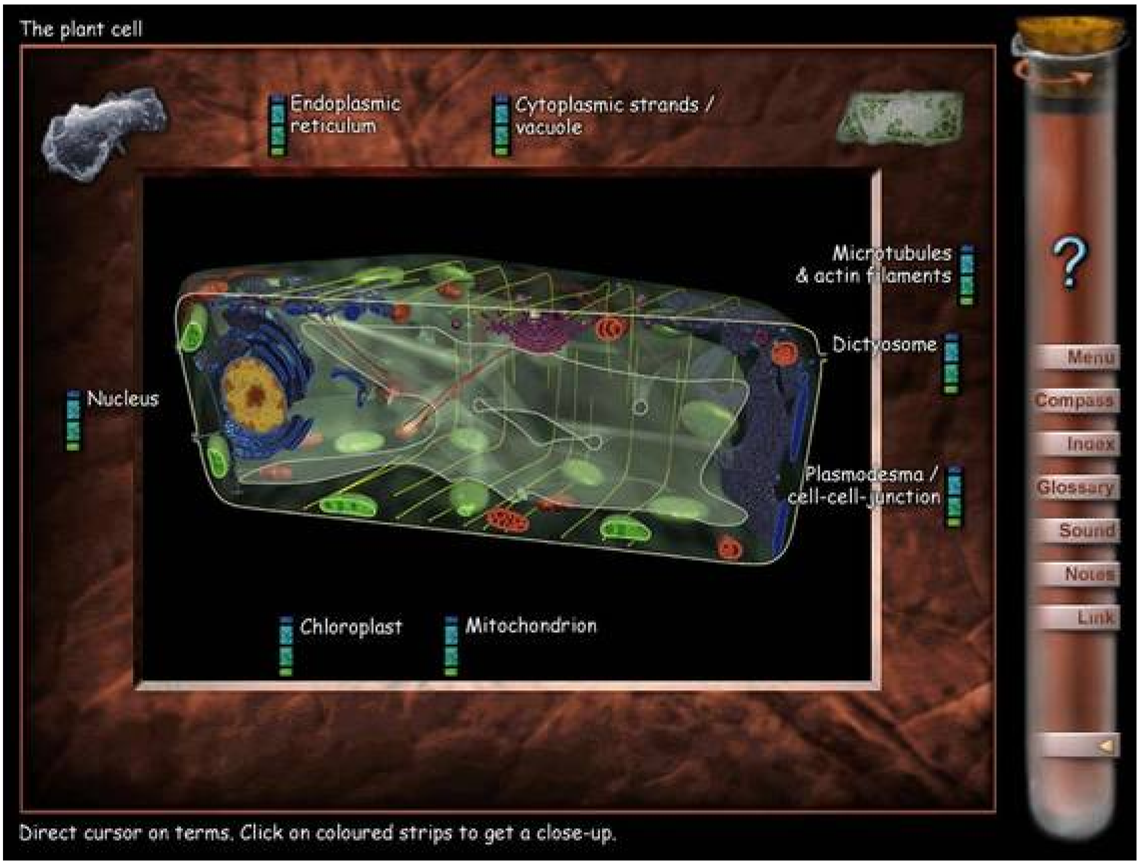

Figure 19 Screen shot of CD variant 2: The plant cell’s cross section. The features of variant 1, i.e. the Quicktime VR model and the flight through the cell, are missing.

CD version 3 – simplification of version 2 with the further reduction of graphical visualization during narration

Version 3 represents a graphical simplification of version 2: the entry screen is the same as of version 2 (see figure 19). However, the click of the term does not open any close-up-view of the cell component in question while the narration is provided. In fact, only during narration the term in question and a connecting line is highlighted (see figure 20).

Figure 20 Screenshot of CD variant 3: The plant cell's cross section – after clicking the model's feature the term "nucleus" is shown while the cell component is highlighted and a narrative explanation provided

CD version 4 – 2D-model of the cell's cross section

In comparison to version 3, version 4 represents yet again a reduction in graphical visualization: while the other 3 variants featured the cross section of the cell as a 3D-model version 4 provides a 2D-model only (see figure 21). As illustrated by the screen shot, after clicking on a term, no close-up-view of the cell component in question is provided while it is explained by the oral commentary.

Figure 21 Screen shot of CD variant 4: The plant cell's cross section – illustration of the cell component after clicking on the term "nucleus" while narration is provided.

2.3.4.2.2 Module "ATP synthase" – the impact of animation design

To take a closer look at the 3D/2D-animations as well as the use of signals/cues 4 variants of the module ATP synthase were produced: the variants differ in a 2x2 factorial design: one factor represents the degree of reality of the animation (two-dimensional vs. three-dimensional) while the other differs in the presence or absence of visual cueing elements or signals (see figure 23) the latter being defined as the highlighting of components in a picture as well as text additions. However, all variants provide the same narration (see table 3).

For realizing the 3D-animation a 3D-software was used: a 3- dimensional grid model was constructed and linked with texture allowing different animations by choice of different camera viewpoints. The 2D-animation drew on vector-based software, here specifically the software Macromedia Flash.

Furthermore, given the advantages of a segmented presentation including e.g. the degree of interactivity possible (see Mayer & Chandler 2001), the animation was modularized arriving at 4 separate entities which can each - apart from playing the animation as a whole – be chosen individually by clicking the buttons 1 to 4 (see figure 22). Moreover, with a click on the inner movie window the animation can be started and stopped.

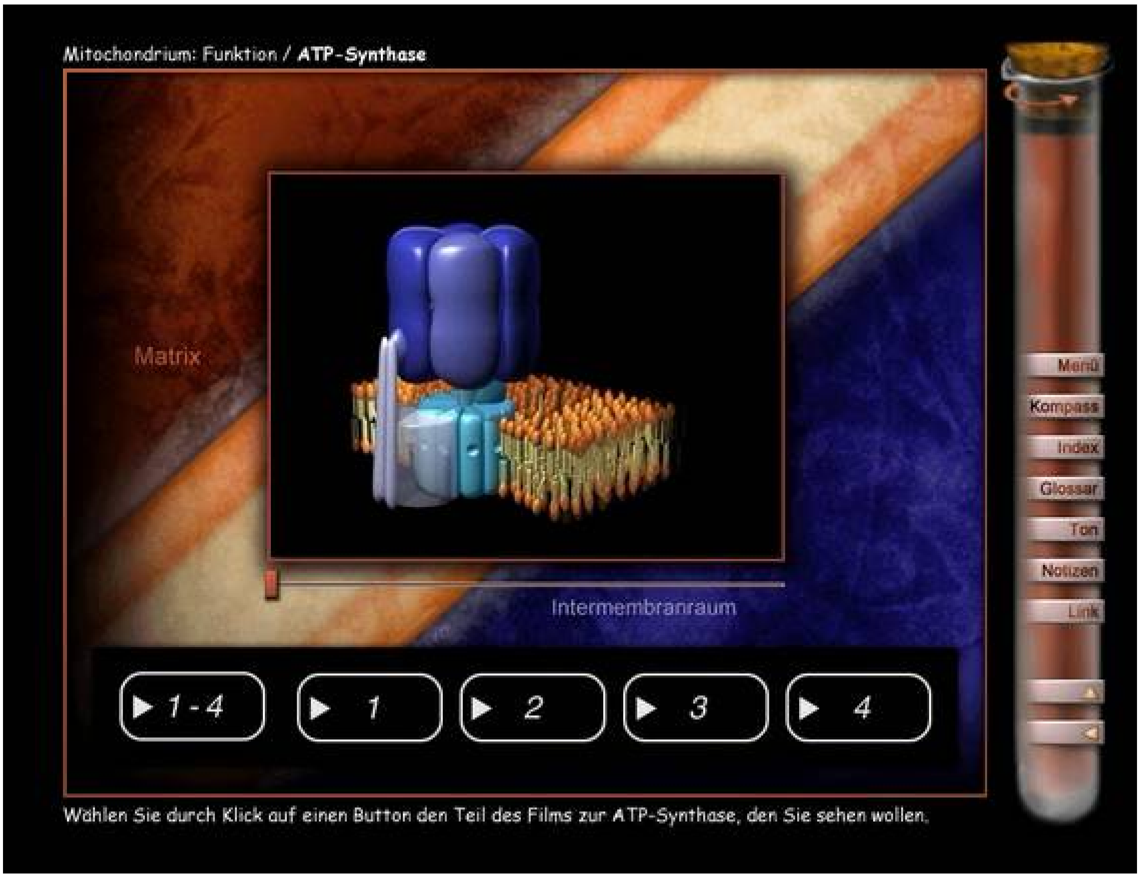

Figure 22 Screen design of the module ATP synthase: Here exemplarily a screen shot of the variant including the 3D-animation is shown

As mentioned above, neither content in general nor narration (for details see table 3) did differ between the four different variants of the software's module ATP synthase. It was the graphical and didactical design of the animation that differed between the single variants: the provision of 3D- or 2D-animations and of cues visualizing the information provided by the narration. Figure 23 compares the graphical design of the four versions of the module ATP synthase.

Table 3 The Narration accompanying the animation ATP synthase

Modularized narration
ATP- the main energy supplier of the cell. How is it generated? A composed molecule, the protein ATP synthase is the key. We can find it in the inner mitochondrial membrane. Two components can be distinguished in accordance to their function: The F0 component consists of a rotating and a fixed part forming a protein channel. The F1 component represents the location where ATP synthesis takes place. It consists of a fixed head and a rotating axis.
The main function of the ATP synthase is the generation of ATP - the ATP synthesis. Necessary for this process is an active respiratory chain, which is explained in another chapter of the CD. In actively respiring mitochondria the proton concentration in the inner space of the mitochondrion – the matrix – is much lower than in the intermembrane space. This difference forms a gradient - the proton motive force.
The proton motive force: it drives the protons through the ATP synthase back into the matrix and in the process causes the mobile complex to rotate. As a result, changes in conformation in the head of the F1 component are induced. They form the basis of the ATP synthesis.
The mechanism is illustrated in a cross section through the F1 complex. Here the three components of the head are shown. Each part consists of the two sub-units alpha and beta which together form a binding site for ADP and phosphate. In the following sequence, the 3 steps of this mechanism will be shown. In the O conformation, the binding site is free. If this state changes into the L conformation, ADP and phosphate are bound. The L form closes to the T conformation. ADP and phosphate react to form the energy-rich ATP, which remains tightly attached to the binding site. On transition from the T conformation to the O conformation, the newly formed ATP is released. This conformation change is achieved by the rotation of the axis. The release of ATP on transition from the T conformation into the O conformation must be forced by provision of energy. Since the rotation of the axis is driven by the flow of protons, ATP synthase thus transforms the proton motive force into chemical energy by generating ATP.

The single text blocks take account of the modularized nature of the animation, i.e. the 4 different parts.

Screen shots of the 4 variants, time: 00:24 min

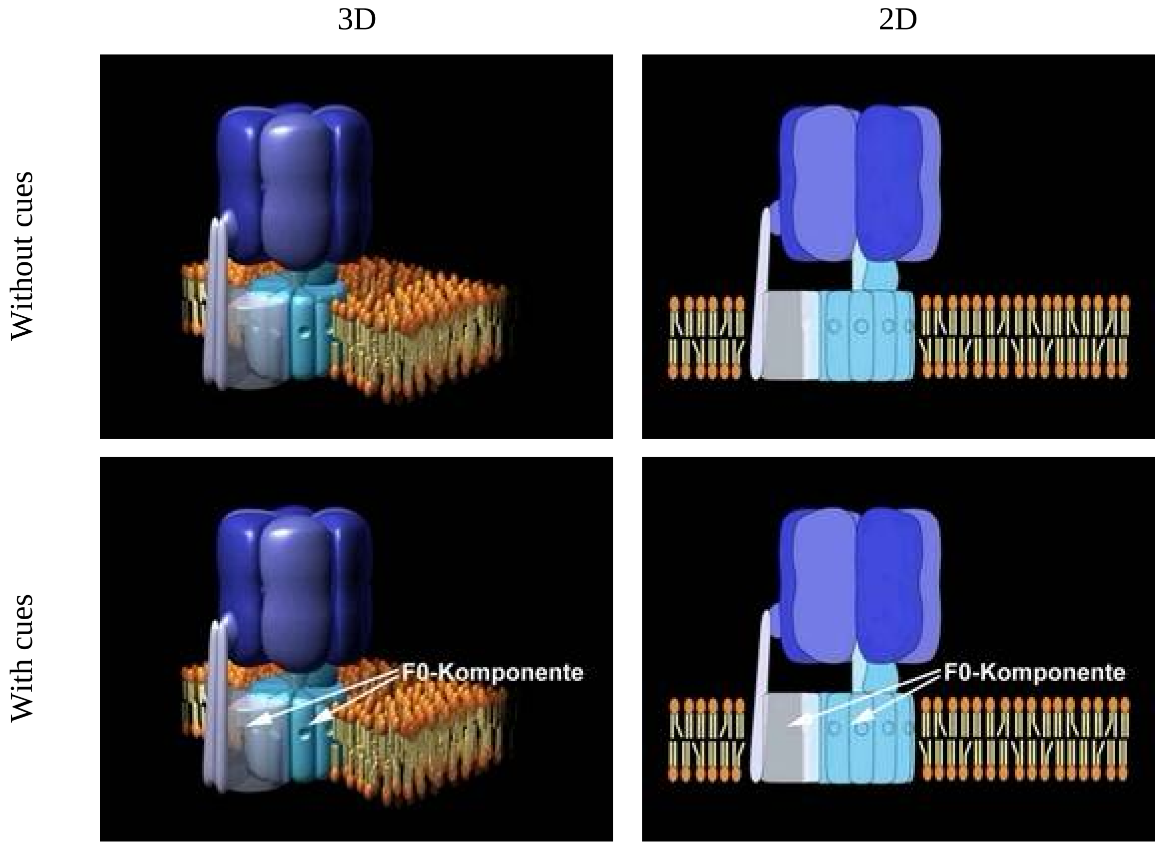

Figure 23 ATP: Comparison of the 4 software variants (time 00:24 min)

Screen shots of the 4 variants, time: 00:37 min

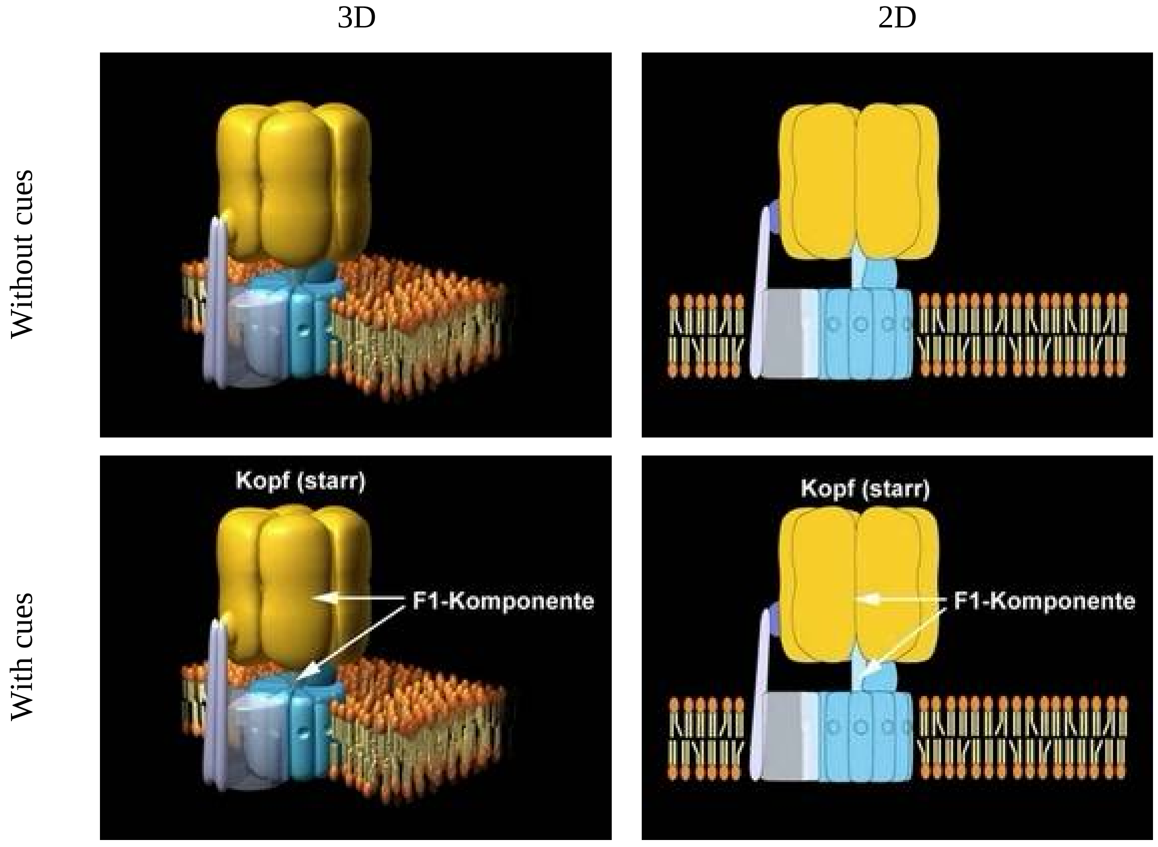

Figure 23 ATP: comparison of the 4 software variants (time 00:37 min)

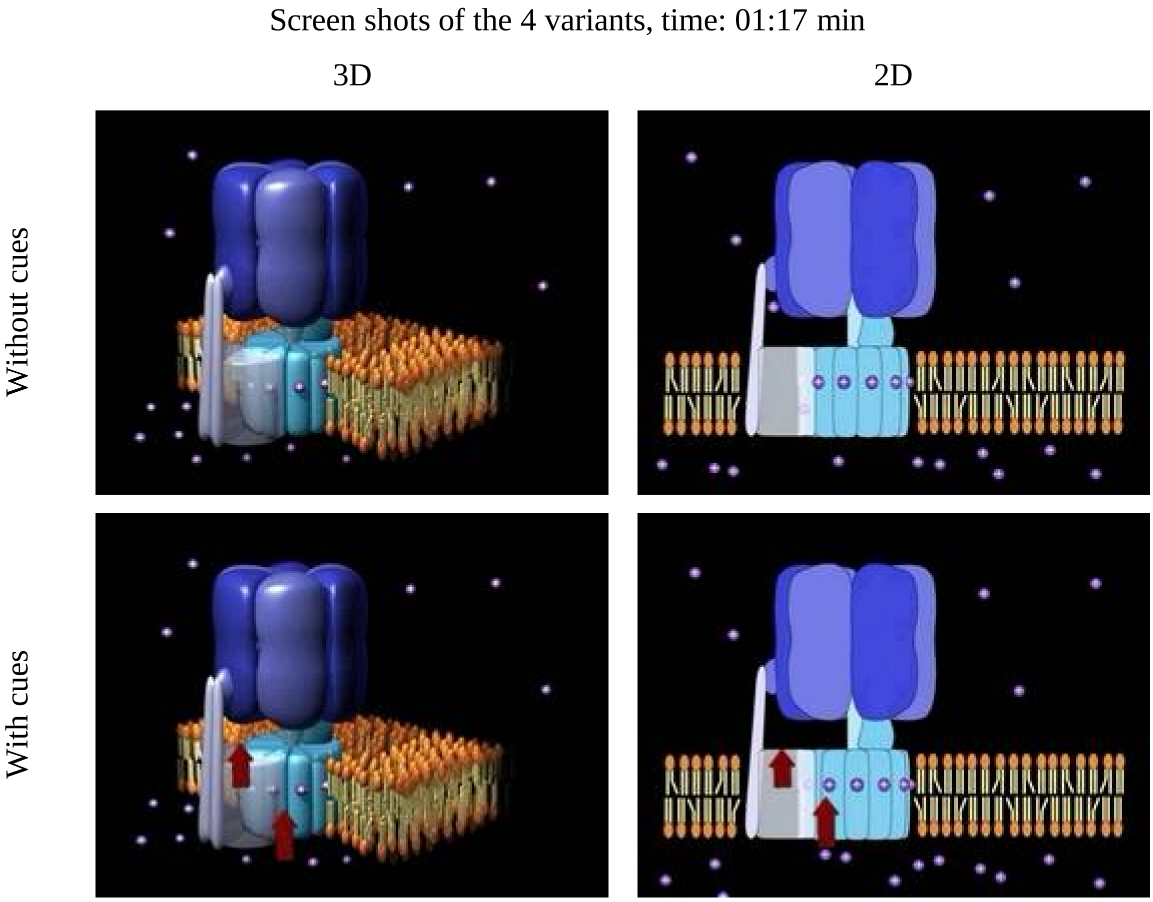

Figure 23 ATP: comparison of the 4 software variants (time 01:17 min)

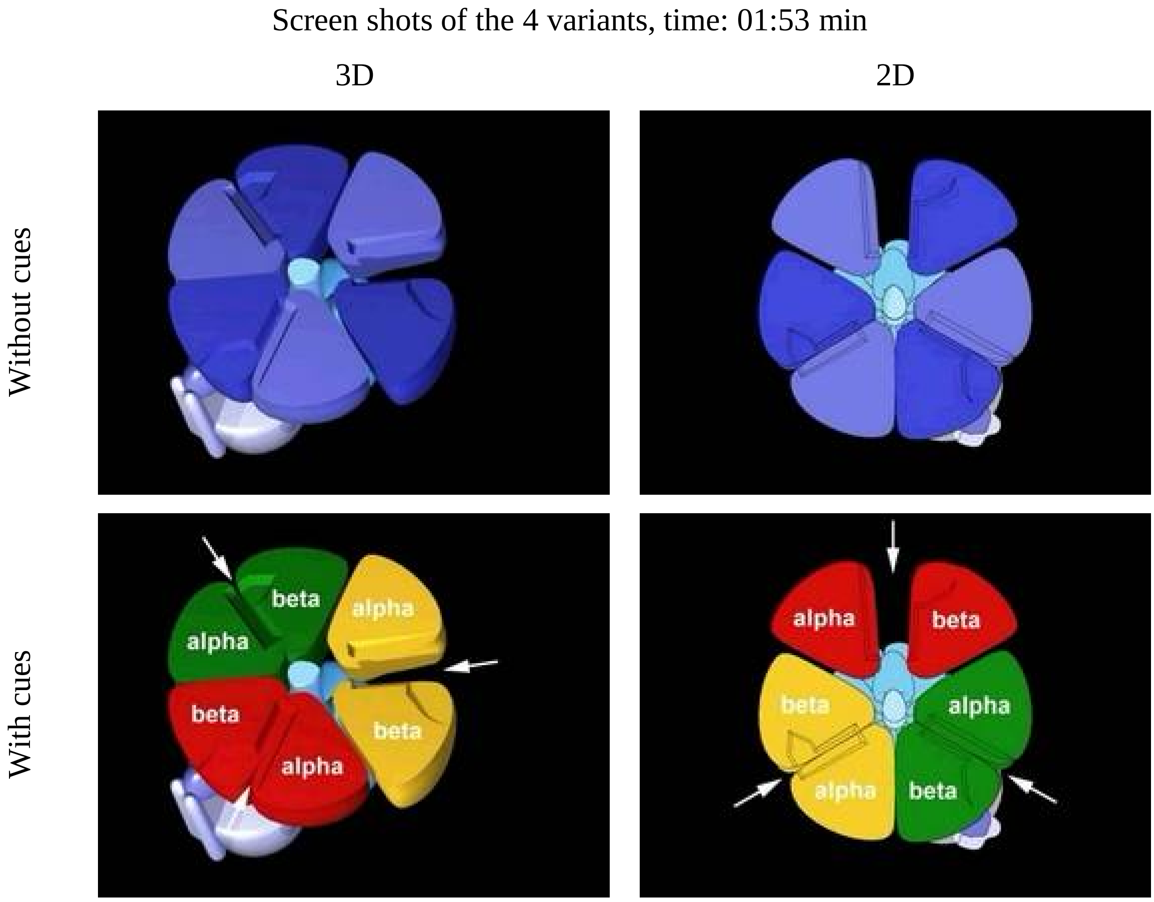

Figure 23 ATP: comparison of the 4 software variants (time 01:53 min)

As outlined above, the 2 variants with signals distinguished themselves by the provision of additional graphical elements and/or highlighted terms or special sections of the animation while narrative explanations of the respective terms were provided (for details see table 4).

Table 4 The cues/signals of the module ATP synthase (in chronological order)

Time (from-to)	Cue/signal
00:23 – 00:30	F0-component
00:25 – 00:26	rotating
00:26 – 00:27	fixed
00:29 – 00:30	protein channel
00:31 – 00:40	F1-component
00:36 – 00:37	head (fixed)
00:38 – 00:40	axis (rotating)
00:50 – 00:53	active respiratory chain
00:59 – 01:06	matrix
01:03 – 01:06	intermembrane space
01:09 – 01:11	proton motive force
01:14 – 01:21	coloured arrow visualizes the path of the protons
01:33 – 01:35	changes in conformation
01:40 – 01:42	cross section
01:44 – 01:59	differentiation of 3 different parts of the head by colour
01:49 – 01:55	alpha / beta
01:52 – 01:55	arrows point to the binding site
02:03 – 02:06	O-conformation
02:13 – 02:15	L-conformation
02:23 – 02:27	T-conformation
02:29	highlighting of the opening of the binding site
02:35 – 03:08	highlighting of the axis

2.4 Data collection and analysis

The data collected consisted of

1. the pre-test questionnaires assessing the learner characteristics (for details see above);
2. the logfiles recording the individual experimentees' or dyads' navigation through the software during the working sessions;
3. the post-test questionnaires on learning outcome and students' evaluation of the software.

After completing the data collection the questionnaires and logfiles were further processed and analyzed. The interpretation of the statistical analyses revealed a complex interplay of usage factors with the CD variants as well as individual learner characteristics.

2.4.1 Field work at schools and universities

Each test series consisted of 3 standardized consecutive sessions with the project team preparing the class rooms for the sessions 1 and 2 beforehand: for the first session the pre-test questionnaires were distributed, for the second session the iMacs were installed incl. the re-arranging of tables to ensure undisturbed working. Directly after the working sessions with the software as well as 2-3 weeks later the learning outcome was assessed in pen-and-pencil tests.

As discussed above, the project's objective was to shed light on the influence of individual learner characteristics as well as software design on the knowledge acquisition process and learning outcome. To investigate these questions a two-fold approach was pursued: individual learner profiles were assessed with the pre-test questionnaires and learning outcome with the knowledge tests after working with the CD-ROM. Moreover the influence of individual and group learning was investigated: in a number of classes learners were asked to work with the software individually with one examinee/computer and no interaction while working. In order to improve the external validity of the test setting further, in a number of classes student groups of two examinees are asked to work jointly with one computer. When there was an unequal number of students in a class, sometimes groups of three student were allowed also. As the investigation on individual and group learning were carried out class-wise no direct comparison of individual and collaborative work but of software impacts on individuals or dyads was possible. The question to be answered concerned the following: Are effects observed in individual learning situations sustained in group working?

The first session was devoted to the introduction of the research project incl. the overview of how data would be collected and processed, including the assurance that individuals' performance would not be shared with the respective teacher/lecturer (for details see annex section). Furthermore the declaration of consent (for details see annex section) was read aloud, discussed, signed by the examinees and subsequently the pre-tests were carried out.

The session's standard schedule is described in the following:

- standardized introduction to the research project: 3 min;
- reading, signing and collection of the declaration of consent: 5 min.

The questionnaires had been placed upside down on the students' working benches. Students were asked not to look/ work through any of the questionnaires before being explicitly encouraged to do so as well as to respect the maximum time allocated for each questionnaire.

- filling in the questionnaire on visual spatial ability: 12 min;
- filling in the questionnaire on prior domain knowledge: 12 min;
- filling in the questionnaire on learning style: 15 min;

The second session was devoted to working with the software (in 2 working sessions) as well as to assessing the learning success and the students' evaluation of the software.

The standard schedule was the following:

- standard introduction to the session's programme, i.e. the work with the software and the subsequent knowledge tests: 3 min
- standard instruction to the first task at hand: 3 min
- first working session of the individual/ of a group of two students with the software – task 1: animal and plant cell: 20 min;

- each examinee/ each dyad was assigned to work with a different variant of the software (with the latter being assigned at random).
- The project team made sure to test all software variants within one class or course to counteract any differences among schools/ universities as well as individual classes regarding prior domain knowledge, computer literacy, etc. that were to be expected. This enabled the project team to later on analyze the data with a randomized complete block ANOVA with the random factor "class" taking account of the heterogeneity among classes (for details see below). The project team supervised the working session a) to ensure that after a max of 5 min all examinees had found the software section to work with; b) to observe and note down the examinees' motivation (i.e. clearly de-motivated students' records were excluded from further analysis to improve logfile data validity (see Nicholas and Huntington 2003).
- filling in a knowledge test on the topic animal and plant cell: 15 min; after a standardized introduction students were asked to fill in a knowledge test focusing with open as well as multiple choice questions on knowledge construction. The test was designed in a manner that students' memory (recall and recognition) as well as understanding (transfer) of the topic animal and plant cell were challenged.
- standard instruction to the second task at hand: 3 min
- second working session of the individual/ of a group of two students with the software – task 2: ATP synthase: 20 min; each examinee/ each group was assigned to work with a different variant of the software the latter being assigned at random. Again it was ensured that all variants were tested in one class.
- filling in a knowledge test on the topic ATP synthase: 15 min; after a standardized introduction, students were asked to fill in a knowledge test focusing with open as well as multiple choice questions on knowledge construction. The test was designed in a manner that students' memory (recall and recognition) as well as understanding (transfer) on the topic ATP synthase were challenged.
- filling in a software evaluation form: students were asked to fill in a questionnaire to evaluate the software's instructional, didactical and graphical value. There was no time limit for this task and students often stayed longer (during their break) to fill it in. The software evaluation by the students marked the end of the second session.

In order to evaluate whether the learning results were stable over time **in a third session** the tests on learning success (i.e. contents-wise the same tests with only the sequence of questions differing) were repeated 2-3 weeks later. The testing was then conducted by the teachers/ lecturers calculating 15 min for each of the two tests. The hard copies of the filled in tests were sent to the project team. To ensure equal conditions during the first and the second knowledge construction test, only students that reported that they had not dealt with the topic in the meantime were included in the analyses.

In accordance with the dissertation's stated objectives the collected data were processed and analyzed to assess the influence of learner characteristics such as visual spatial ability, prior domain knowledge and learning style as well as the software design on the knowledge acquisition process. To this end the questionnaires as well as the logfiles were analyzed.

2.4.2 Reliability of questionnaires

All questionnaires were submitted to reliability analyses in order to ensure that the single questions/items pulled together for each questionnaire would overall support meaningful tests, i.e. by applying a number of criteria single topics were tested whether or not they were useful for the overall test. To this end the questionnaires were first of all piloted with 100 students thereby identifying and taking out the questions that had proofed to be too easy or too difficult and/or in any other way not fitting in the context of the study.
Furthermore, all questions relying on a right-wrong answer or a scale ranking, e.g. the range from "very often" to "never", were submitted to further analyses. In these cases the reliability coefficient as the measurement of the accuracy with which an item is described by the test was calculated. Statistical software programmes offer several methods for its calculation. In the study presented Cronbach's Alpha (with values between 0 and 1 (excellent reliability)) was calculated with SPSS. As mentioned above, the learning style index LSI reliability had to be high to avoid misinterpretations: only examinees whose results led to a Cronbach's alpha of about 0,7 to 0,8 (i.e. about one quarter to one third of the whole sample group) were included in further analysis.

2.4.3 Analysis of questionnaires

The questionnaires were analyzed in the following manner:

- Visual spatial ability: as mentioned above, the test features 21 different sets of pictures. Students were classified as possessing high/low spatial ability by means of a median split with regard to their performance (i.e. the correct answers provided) in the tube figures test.
- Prior domain knowledge: the test results were calculated as the sum of scores of the single questions. With a median split the students were grouped into learners with high or low prior domain knowledge.
- Learning style: the tests were analyzed with the help of a scoring sheet and in accordance with instructions provided by the test's developers (for details see the annex section). To correlate the factor learning style with any other factor investigated, only the examinees with a pronounced tendency towards one style were included in the further analyses (see above).

The resulting scores of all questionnaires per examinee were fed into an Access database.

2.4.4 Tracking and analysis of logfiles

One way to capture the utilization and efficiency of learner-controlled multimedia environments is documenting an individual's movement through these environments. By collecting information regarding the selections an individual makes (i.e. choosing text-based screens, digitized movies, etc), the sequencing of these different screens and the time spent processing the various components of the environment, researchers are afforded a non-intrusive window into knowledge acquisition strategy, information search and problem solving (Gerjets & Scheiter 2003; de Jong & van der Hulst 2002; Barab et al. 1996).

In accordance to literature (see above) the learning process, i.e. the individuals or groups' navigation through the software, was documented by encoded log-files. As described elsewhere, the log-file tracking functionality had been integrated into all software variants. Thereby it was ensured that the computer recorded each screen selected, the order in which screens were selected as well as the length of time spent on each screen. The encoded log files were recorded in the log pad programme of the individual iMacs local drive. The encoded log files of each examinee were transferred to an Excel table (for a sample list of log files see the annex section) for further analysis. Log files of computers with technical problems or participants who had shown very limited motivation during the testing session (which was likely to result in log files of limited validity; see Nicholas & Huntington 2003) were not included in further analyses.

Since log files contain enormous amounts of data, methods for data reduction with a minimum loss of information are needed (Richter et al. 2003). The analysis of logfiles, i.e. software usage, was performed in a number of different steps:

- With the help of pivot tables 23 (cell) to 27 (ATP) different usage variables, selected for their strong predictive potential, were extracted from the log files. They either measured the number of clicks or the time span of a screen's use. This analysis step resulted in one value for each usage variable per participant/dyad. The usage variables could be categorized in one of the four software component groups as described earlier and shown in table 5.
- To condense the information inherent in the comparably large number of variables to a limited number of meaningful (dependent) variables or usage factors and to test the factors' validity, a principal component analysis (PCA) was performed. With this analysis eight (cell) to eleven (ATP) factors impacting on navigation, learning support and content level were identified. The chosen spectrum of methods allowed the condensation of more than 60 000 lines of log file data to a small number of relevant usage factors. The resulting usage factors are presented and discussed in the respective results & discussion chapters.
- To test the hypotheses parametrical and non-parametrical statistical tests were calculated with the usage factors resulting from the principal component analysis considered as the dependent variables and the learner characteristics as assessed in the pre-tests as well as the software design as independent variables.
- The interpretation of the statistical tests revealed that learner characteristics and software design features indeed impact on the use of the software and the learning process (for details see results & discussion chapters).
- Furthermore, the correlations as regards the learning success as well as the individual's evaluation of the software were drawn.

In the following sub-chapters the processing of the logfiles is described in further detail.

2.4.4.1 Data quality management of logfiles

First of all the log files were checked to ensure that the logged data presented were plausible and stringent. Due to the way the log file tracking functionality had been programmed some entries were misleading, e.g. depending on the previous page visited one and the same screen was encoded in different ways. Furthermore, not all entries of one variable were summed up correctly. This is why a very work- and time-intensive step to check data plausibility and validity had to be introduced, with no technical support available but to go through the 60 000 lines of log file data manually.

2.4.4.2 Selection and calculation of usage variables

- From the log file data 23 (cell) to 27 (ATP) dependent variables were selected for further analysis because of their strong predictive potential. They were classified into four different groups to reflect the four software components groups described in the introduction:
    - i) navigation features;
    - ii) learning support features;
    - iii) to-be-learned content: audiovisual content collection;
    - iv) to-be-learned content: content nodes/modules (cell / ATP).

  The selected usage variables, their classification to one of the four software groups and the feature measured with this variable are shown in table 5.
- By means of pivot tables for every variable the “time on screen” and “number of clicks” was calculated per participant, resulting in one value for each variable. The pivot table format was chosen as it represents a method that allows the exchange of rows, columns and levels so that results can be obtained from different viewpoints.
- Sessions shorter than 15 minutes and longer than 25 minutes were excluded from further analysis. To make the different variables comparable all were adjusted to a standard of 20 minutes.

Table 5 Selected usage variables

usage variables and their software component grouping	*explanation regarding the respective feature of the hypermedia learning environment that is measured with the variable*
navigation features	
start of sitemap (st)	clicks on the button “compass” on the start screen (st)
start of sitemap (tt)	clicks on the button “compass” on the test tube (tt)
time on sitemap	total time on the screen “compass”
start of explorative tour	clicks on the button “explorative tour” on the start screen
start of guided tour	clicks on the buttons “function of mitochondria” and “structure and reproduction” on the start screen leading to a guided tour
time on guided tour	total time on both guided tours
clicks on menu	clicks on the button “menu” on the test tube
clicks on index	clicks on the button “index” on the test tube
clicks on back button	clicks on the button with an arrow to the left to get to the previous screen
clicks on button “one page up”	clicks on the button with an arrow to the top to get to the screen of the higher hierarchy level
clicks on link	clicks on the button “link” of the test tube
learning support features	
clicks on glossary	sum of clicks on different terms in the glossary
clicks on quiz	total number of clicks on the questions of the quiz
clicks on quiz videos	clicks to choose a new quiz video
time on quiz video	total time on quiz videos
clicks on notes	clicks on the button “notes” on the test tube
time on open notes	total time with an open notepad
audiovisual content collection	
time on cinema	total time on the collection of films that can be chosen with the buttons “all films” on the sitemap or “cinema” on the test tube
time on 3D-lab	total time on 3D-lab that can be chosen with the respective button on the sitemap or the test tube
control of films and animations	clicks on the movie player features or directely on the inner movie window to control films and animations of the cinema and 3D-lab

Table 5 Selected usage variables

usage variables and their software component grouping	*explanation regarding the respective feature of the hypermedia learning environment that is measured with the variable*
content module on the cell	
total time on cell	total time on the whole cell content module, including the 3D-models and cell flights in CD version 1; in CD versions 2 – 4 identical with time on cross section of the cell
time on cross section of the cell	total time on the cross section of the cell
clicks on terms in cross section	clicks on the terms of the cross section starting a narration with an explanation of the organelles of the cell and opening up close-up-views in CD versions 1 and 2
content module on ATP	
time on content module ATP	total time on the content module ATP
time on animation ATP 1-4	total time watching the whole animation after clicking on the button "1-4"
control of ATP animation	clicks on the inner movie window to start and stop the animation on the ATP synthase
time on sequence ATP 1	total time watching this ATP sequence after click on "1"
time on sequence ATP 2	total time watching this ATP sequence after click on "2"
time on sequence ATP 3	total time watching this ATP sequence after click on "3"
time on sequence ATP 4	total time watching this ATP sequence after click on "4"

The variables were selected due to their strong predictive potential and classified to one of the 4 software components. The explanation describes what is measured with the respective variable.

2.4.4.3 Principle component analysis (PCA)

For any given number of variables that are assumed to have an influence on a certain outcome, the challenge is to check whether the variables identified actually influence that outcome independently. In case of interdependencies among the variables the models explaining cause and effect will be distorted. This is why the extraction of the main independent influence factors from a multitude of possible variables is called for. The factor analysis, here specifically the principle component analysis, allows the reduction of a comparably large number of different variables to a smaller number of independent main factors of influence. In doing so it is ensured that variables with strong correlations among themselves are combined to one factor. Variables of different factors correlate only to a very limited extent. The objective of the factor analysis can therefore be seen in the identification of those factors that explain the interplay of a given number of variables most comprehensively. Accordingly, by conducting a principle component analysis (PCA) the standardized variables were condensed to a smaller number of factors. The chosen spectrum of methods allowed the condensation of more than 60 000 lines of log file data to a small number of relevant usage factors. The process of condensation from the original usage variables to the resulting main usage factors are described in the following:

Identification of main usage factors

After selecting meaningful original variables (see table 5) that are fundamental for the quality of results of a principle component analysis eight (cell) to eleven (ATP) main usage factors impacting on navigation, use of learning support features and content were identified by a calculation with SPSS 12 for windows (rotation method: Varimax; selected number of factors according to the Kaiser-criterion). The identified main usage factors served as new dependent usage variables for further statistical analyses (for details see below).

Interpretation of main usage factors

The correlations between the original usage variables and the main usage factors are summarized in a correlation matrix. In this matrix factor loads represent the strength of correlation between every original variable and the different main usage factors. In accordance to Backhaus et al. (2003) the resulting usage factors were interpreted on the basis of those original usage variables that had a factor load stronger than $\pm$ 0,5 on the respective usage factor. The latter are presented in the sections below as well as in the results and discussion chapters.

Further statistical calculations with the main usage factors

For further statistical analyses (see next section) it is necessary to have individual values for each user that express the intensity of use with respect to each main usage factor. These are called factor values and based on the values of the original user variables such as “number of clicks” or “total time on screen” and they are calculated automatically for each user and usage factor by statistical programmes such as SPSS. Thereby, the values of the original user variables can serve as a basis for further statistical calculations to analyze the impact of learner characteristics or software design features on the software use. The means of factor values for each user group (e.g. high/low visual spatial ability) or each software design feature (e.g. 3D/2D-design) are presented graphically together with tables that show the mean values of the original user variables (e.g. time on screen) in the respective sections of the result and discussion chapters.

Additional calculation of original variables

The content modules on the cell and on the ATP synthase play a central role in the knowledge acquisition process to solve the tasks given to the students. To get a more detailed picture of the use of software modules in question, i.e. animal and plant cell as well as ATP synthase, the impacts of learner characteristics and software design properties/parameters on three original usage variables of each module were directely analyzed: e.g. total time on the module cell, time on the cross section of the cell, clicks on terms in cross section; total time on content module ATP, time on animation ATP 1-4 and control of ATP films. However, these variables were also processed by the PCA to verify data plausibility.

2.4.4.4 Parametrical and non-parametrical statistics

To test the hypotheses parametrical and non-parametrical statistical tests were calculated with the main usage factors resulting from the principal component analysis used as dependent variables and the learner characteristics and software design (e.g. 3D/2D-design; presence/absence of visual cues) as independent variables.

In order to analyze the variables’ distribution first of all a Kolmogorov-Smirnov-test was conducted. Depending on the distribution of the data of the usage factors (normal vs. non-normal distribution) subsequently either parametrical or non-parametrical statistics were applied to test the hypotheses.

In case of normal distribution (Kolmogorov-Smirnov-test, $p > 0,05$) analyses of variance could be calculated: these analyses investigate the influence of one or more independent variables on one dependent variable. In the cell experiment contrasts were calculated when ANOVA revealed a significant difference between the four software versions. These contrasts test the significance of usage differences from one software variant to the next (1/2: with/without models; 2/3: with/without close-up-views; 3/4: 3D- or 2D-static picture design).

In case of non-normal distribution (Kolmogorov-Smirnov-test, $p \leq 0,05$), i.e. the data were skewed, non-parametrical tests were calculated. In these tests not the values as such but their ranking on the rating scale are analyzed, this is why these tests are not sensitive to statistical anomalies. In case of the four software versions in the first step Kruskal-Wallis-H-tests were conducted to compare the 4 independent variables. When H-tests revealed a significant usage difference between the four software versions, subsequently Mann-Whitney-U-tests were calculated to test the significance of usage differences from one software variant to the next (1/2: with/without models; 2/3: with/without close-up-views; 3/4: 3D- or 2D-static design).

Taking human resources and time constraints into account, it was decided to focus the present study on the investigation of the impact of various factors on the hypermedia use in a realistic learning scenario, with the comprehensive analysis of the factors' interactions to follow at a later stage. Against this background, the impacts of the different learner- and software-related factors were studied in separate analyses without integrating all possible combinations of independent and dependent variables. The following results and discussion chapters focus on the dissertation's hypotheses assessing whether

a) content design differences have an impact on content use but also on navigation and the use of learning support tools;

b) content design impacts are different on students learning individually or in dyads;

c) prior domain knowledge, spatial ability and learning style have an impact on different levels of software use, i.e. content, learning support and navigation.

3 Results

As outlined in detail in the methods chapter, the students were asked to work either individually or in dyads with one of the four different software versions of the hypermedia learning environment while logfiles were recorded. The usage variables selected for further analysis were the same for individuals and groups. However, a principle component analysis was carried out seperately for individual and collaborative use to assess whether the resulting main usage factors were similar: the major goal was not to compare individual and group use directly but to test if the effects and impact of software design remained, changed or vanished investigating individual as well as collaborative use.

Structure of result presentation

The results are presented in the following two subchapters:

Section 3.1 focusses on the influence of 3D-models, close-up-views and 3D/2D-design of a static picture on hypermedia use (for details see methods chapter).

Section 3.2 presents the influence of animation design - 3D- vs. 2D-design as well as the presence or absence of signals on learning with hypermedia (for details see methods chapter).

In both sections the impact of content design on hypermedia use is presented for individual and collaborative learning (dyads). A comparison of the log files revealed that the impact of content design on dyads and individuals differs in dependence of the respective software design parameter investigated.

Moreover, the influence of learner characteristics was analyzed and is presented for students learning individually. The impact of the latter was not investigated for each software version separately but generally.

The wealth of variables analyzed calls for result summaries which are presented at the end of each subchapter.

It should be mentioned also that in line with German conventions the numerical values below one were distinguished with a comma (not a dot).

The general mode of result presentation is illustrated in the following. In a first step the dependent variables (main usage factors and original usage variables of the content modules cell and ATP) are presented and in a second step the impact of the independent variables (content design and learner characteristics) on these dependent variables are shown.

<u>1. Presentation mode of the dependent variables (main usage factors and original usage variables of the content modules cell and ATP)</u>

In each result subchapter first a table with the main usage factors resulting from the principle component analysis is presented. As described in the methods chapter, each main usage factor is interpreted on the basis of the original usage variables loading stronger than 0,5 on the respective usage factor. Accordingly, the table shows the main usage factors together with the original variables loading stronger than $\pm$ 0,5. If the original usage variables load negatively on a main usage factor they have to be interpreted inversely to those loading positively, i.e. a high mean factor value has to be interpreted as less intensive use.

Additionally, some of the usage variables that were considered of central importance for the respective task given to the students, e.g. “total time on cell”, “time on cross section of the cell”, “clicks on terms in cross section”, “time on content module ATP”, “time on animation ATP 1-4” and “control of ATP animation”, were analyzed and presented directly.

<u>2. Presentation mode of the impact of the independent variables (content design and learner characteristics) on the dependent variables (main usage factors and usage variables of the content modules cell and ATP)</u>

Following a standard presentation mode, the results for the impact of the different independent variables on hypermedia use are presented seperately:

- a table summarizes the results of the parametrical and non-parametrical tests for each main usage factor as well as the original usage variables that measure the intensity of use of the content modules “cell” and “ATP” respectively;

- in case the statistical tests reveal a trend or a significant impact, the respective main usage factor or original usage variable are presented with further tables and figures illustrating the influence on content use, navigation behaviour and the use of learning support features. These result presentations include

- tables that show the descriptive data of the different original usage variables in case they were calculated directely, e.g. mean number of clicks or mean time on screen with respect to software design parameters and learner characteristics;
- tables that show the descriptive data of each main usage factor, i.e. a mean factor value with respect to software design parameters and learner characteristics. These factor values are the basis for the statistical tests and are presented in italics. Additionally, the mean number of clicks and/or the mean time on screen of the

original usage variables that were used for interpretation of the respective main usage factor are shown (M = mean; SE = standard error; N = number of students);

- figures illustrating usage differences with respect to the main usage factors as well as the original usage variables.

3.1 Module "plant and animal cell"

3.1.1 Individual learning

In this chapter the results for students using the software individually are presented. The main usage factors resulting from the principle component analysis were further analyzed with respect to the impact of the visual content representation, i.e. the presence of 3D-models, close-up-views and the dimensionality (3D/2D) of a static picture of the cell as well as with respect to the learner characteristics prior domain knowledge, spatial ability and learning style.

3.1.1.1 Main usage factors

8 main usage factors resulted from the principle component analysis. Table 6 shows the usage variables loading on the respective main usage factor. As described above, some variables load negatively.

Table 6 Cell - individual learning – main usage factors & variables

main usage factor	*variables (load strength in parentheses)*
use of cell content	total time on cell (0,95) time on cross section of the cell (0,96) clicks on terms in cross section (0,93)
use of audiovisual content collection	time on 3D-lab (0,89) control of films and animations (0,83) time on cinema (0,53)
use of quiz and quiz videos	clicks on quiz (0,78) clicks on quiz videos (0,96) time on quiz videos (0,92)
use of notes	time on open notes (0,93) clicks on notes (0,92)
use of sitemap or guided tour	start of sitemap (tt) (0,84) time on sitemap (0,84) start of guided tour (- 0,60) time on guided tour (- 0,64)
start of sitemap and use of back button	start of sitemap (st) (0,83) clicks on back button (0,56)
start of explorative tour and use of back button and glossary	start of explorative tour (0,75) clicks on back button (0,58) clicks on glossary (0,50)
use of pre-defined links	clicks on one page up button (0,71) clicks on link (0,66)

Main usage factors and the usage variables loading on them ≥ 0,5 and ≤ -0,5.

Usage variables not loading with at least 0,5 on any main usage factor were

- “clicks on index” with the strongest load of 0,46 on “start of explorative tour and use of back button and glossary”, and
- “clicks on menu” with the strongest load of 0,43 on “use of pre-defined links”.

Therefore, the latter were were not considered for the further interpretation of the main usage factors.

The usage variable "clicks on back button" was loading stronger than 0,5 on two main usage factors:

- "start of sitemap and use of back button", and
- "start of explorative tour and use of back button and glossary".

Therefore this usage variable was used for interpretation of both main usage factors.

<u>Normal and skewed distribution of main usage factors</u>

The resulting main usage factors served in the further analysis as dependent variables. The Kolmogorov-Smirnov test showed a normal distribution of the usage variables "total time on cell", "time on cross section of the cell" and "clicks on terms in cross section" as well as of the main usage factors "use of sitemap" and "start of sitemap and use of back button". Accordingly, for these factors ANOVAs were calculated with respect to usage differences. As the other main usage factors showed a skewed distribution, usage differences were calculated with H and U tests.

3.1.1.2 Impact of 3D-models, close-up-views and static picture design

The analysis of the impact of software design was carried out with 247 students. Table 7 shows the distribution of the students to the different software versions.

Table 7 Cell – individual learning - content design - distribution of students to CD variants

CD version 1	CD version 2	CD version 3	CD version 4
N = 63	N = 65	N = 65	N = 54

Table 8 provides an overview of the p-values of parametric and non-parametric statistics while using the CD variant as independent and the main usage factors as dependent variables. When the result of the ANOVA or H test calculated for all four CD variants showed a trend or a significant effect, a-priori contrasts or U tests were calculated for each software design parameter:

1) CD version 1/2: with/without 3D-models
2) CD version 2/3: with/without close-up-views
3) CD version 3/4: with a 3D/2D-static picture of the cell’s cross section

Table 8 Cell – individual learning – impact of content design on hypermedia use – p-values

	CD 1-4	*CD1/2: with/without 3D- models*	*CD 2/3: with/without close-up-views*	*CD 3/4: 3D/2D-static*
total time on cell	0,001	0,001 (with)	0,097 (without)	0,832
time on cross section of the cell	0,182	-	-	-
clicks on terms in cross section	0,037	0,494	0,010 (without)	0,650
use of audiovisual content collection	0,216	-	-	-
use of quiz and quiz videos	0,003	0,120	0,112	0,794
use of notes	0,822	-	-	-
use of sitemap (positive load on main usage factor)	0,006	0,008 (with)	0,072 (without)	0,994
use of guided tour (negative load on main usage factor)	0,006	0,008 (without)	0,072 (with)	0,994
start of sitemap and use of back button	0,745	-	-	-
start of explorative tour and use of back button and glossary	0,255	-	-	-
use of pre-defined links	0,770	-	-	-

p-values of ANOVA (a-priori contrast for single CD versions) and H test (U test for single CD versions) for usage variables and main usage factors. The entries in parentheses show which design feature (e.g. with or without 3D-models) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.1.1.2.1 Use of the cell content

ANOVA revealed a significant difference regarding the total time on the module “cell” among the four software versions (p=0,001). These differences are mainly based on the dissimilar use of the CD versions 1/2 “with/without 3D-models” (a-priori contrast, p=0,001) and 2/3 “with/without close-up-views (a-priori contrast, p=0,097) with the content module “cell” being used more intensively when 3D-models were present and close-up-views absent.
There was also a significant difference in the number of clicks on the cross section of the cell (p=0,037). This result may be based on a different use of the CD versions “with/without close-up-views (a-priori contrast, p=0,010) with more clicks on the terms when close-up-views were absent.

The comparison of the CD versions with a two- or three-dimensional presentation of a static picture revealed no differences for content use. The results are presented in further detail in table 9 as well as in the figures 24 and 25.

Table 9 Cell – individual learning – the impact of content design on content use

	CD version 1 N = 63		CD version 2 N = 65		CD version 3 N = 65		CD version 4 N = 54	
	M	SE	M	SE	M	SE	M	SE
total time on cell	589,1	28,1	403,4	25,9	465,4	27,4	457,1	25,7
time on cross section of the cell	403,7	25,8	403,4	25,9	465,4	27,4	457,1	25,7
clicks on terms in cross section	18,0	1,4	16,7	1,3	21,8	1,6	20,8	1,4

Impact of content design on the use of the cell content: time (seconds) and number of clicks.

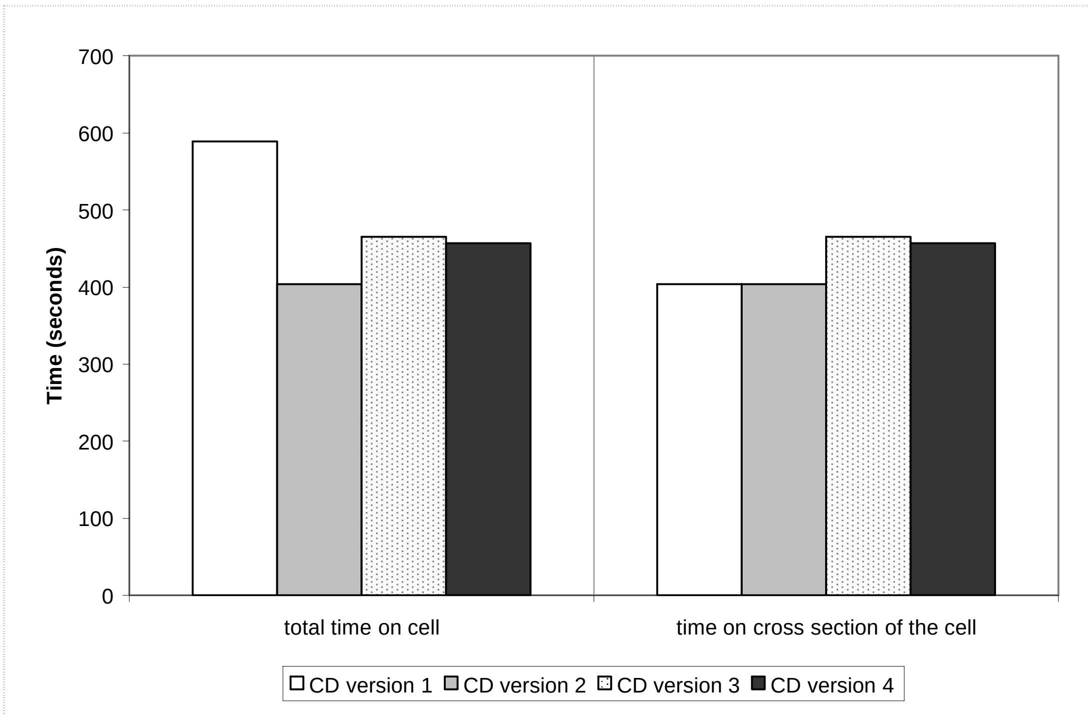

Figure 24 Cell – individual learning – the impact of content design on content use (time)

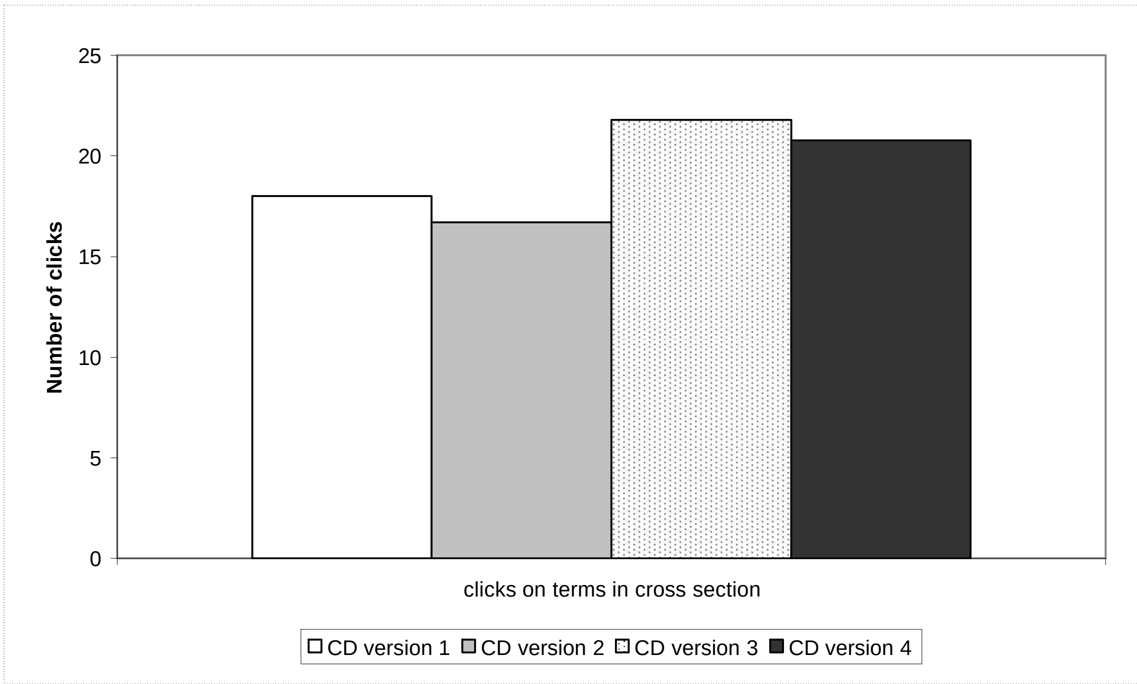

Figure 25 Cell – individual learning – the impact of content design on content use (clicks)

3.1.1.2.2 Navigation and use of learning support features

Regarding the use of the sitemap ANOVA showed a highly significant difference between the four software versions (p=0,006). These differences are mainly based on a dissimilar use of the CD versions “with/without 3D-models” (a-priori contrast, p=0,008) and a trend between the software variants “with/without close-up-views (a-priori contrast, p=0,072) with the sitemap being used more intensively when 3D-models were present and close-up-views absent. This was also the pattern emerging when analyzing the use of the content module “cell” as such. The comparison of the CD versions with a three- or two-dimensional presentation of a static picture revealed no differences in navigation and the use of learning support features.

The H-test according to Kruskal and Wallis revealed a highly significant difference in the use of quiz and quiz videos (p=0,003) between the four CD versions. However, subsequent U-tests for each pair of software variants failed to meet even trend levels (CD 1/2 “with/without 3D-models”, p=0,120; CD 2/3 “with/without close-up-views, p=0,112; CD 3/4 3D-static/2D-static, p=0,794). The descriptive data revealed that a decrease in the visual details of the content presentation led to an increase in the use of the quiz and quiz videos. The results are presented in further detail in table 10 as well as in figure 26.

Table 10 Cell – individual learning – the impact of content design on navigation/learning support

	CD version 1		CD version 2		CD version 3		CD version 4	
	N = 63		N = 65		N = 65		N = 54	
	M	SE	M	SE	M	SE	M	SE
use of sitemap or guided tour	*0,199*	*0,120*	*-0,272*	*0,129*	*0,042*	*0,128*	*0,044*	*0,126*
start of sitemap (tt)	4,5	0,5	3,4	0,5	4,7	0,6	4,2	0,5
time on sitemap	45	4,3	37,1	4,0	46,2	4,1	44,9	4,4
start of guided tour	0,8	0,1	1,4	0,2	1,2	0,2	1,0	0,1
time on guided tour	115,8	23,5	251,8	36,1	194,9	33,7	162,4	30,2
use of quiz and quiz videos	*-0,249*	*0,062*	*-0,065*	*0,113*	*0,090*	*0,122*	*0,261*	*0,193*
clicks on quiz	1,4	0,5	2,3	0,8	3,5	1,0	3,9	1,1
time on quiz videos	3,1	1,9	9,8	4,7	11,4	3,7	22,4	9,1
clicks on quiz videos	0,1	0,07	0,2	0,1	0,4	0,1	0,5	0,2

Impact of content design on navigation and the use of learning support features: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on the respective main usage factors.

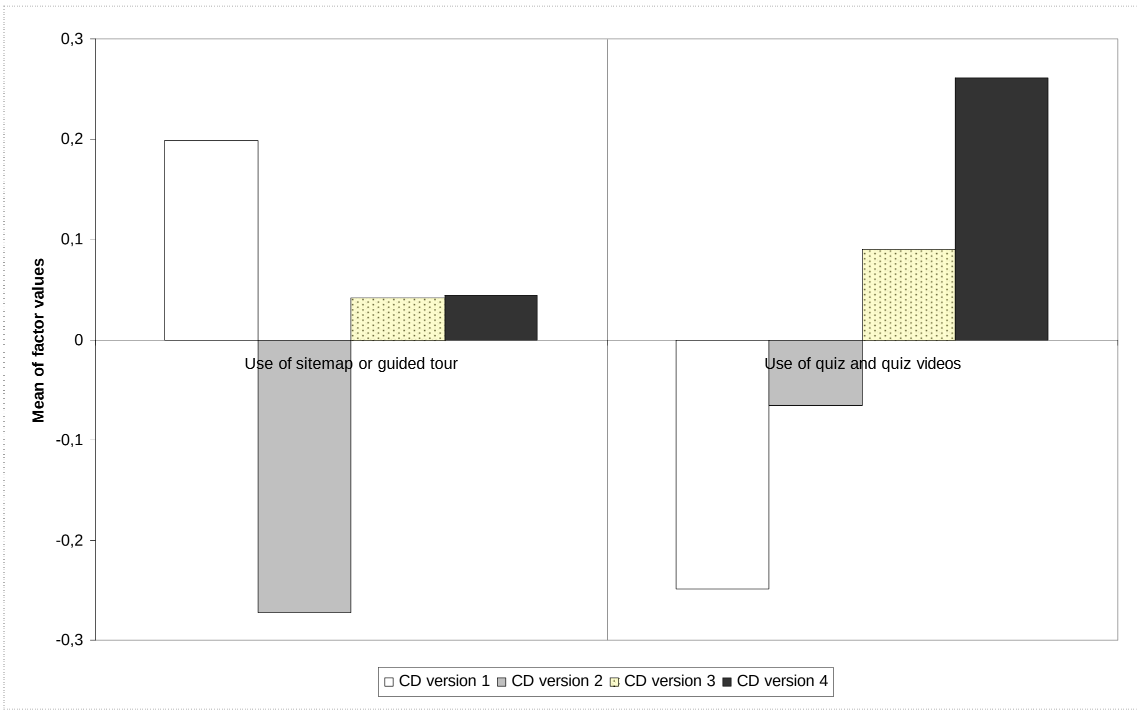

Figure 26 Cell – individual learning – the impact of content design on navigation and the use of learning support features: factor values of the respective main usage factors

3.1.1.3 Impact of prior domain knowledge and spatial ability

The analysis of the impact of prior knowledge was carried out with 226 students, the analysis of the impact of spatial ability with 225 students. Participants were classified by median split to have low and high prior domain knowledge and spatial ability. Table 11 shows the distribution of the students to the different groups.

Table 11 Cell – prior knowledge / spatial ability – distribution of students

Prior domain knowledge		Spatial ability	
low	high	low	high
N=116	N=110	N=114	N=111

Table 12 provides an overview of the p-values for parametric and non-parametric statistics with prior domain knowledge and spatial ability serving as independent and the original usage variables as well as the main usage factors as dependent variables.

Table 12 Cell – impact of prior domain knowledge / spatial ability on hypermedia use – p-values

	Prior domain knowledge	*Spatial ability*
total time on cell	0,059 (low)	0,153
time on cross section of the cell	0,017 (low)	0,103
clicks on terms in cross section	0,013 (low)	0,033 (high)
use of audiovisual content collection	0,871	0,029 (low)
use of quiz and quiz videos	0,254	0,224
use of notes	0,167	0,054 (high)
use of sitemap or guided tour	0,479	0,136
start of sitemap and use of back button	0,038 (low)	0,149
start of explorative tour and use of back button and glossary	0,067 (low)	0,542
use of pre-defined links	0,904	0,018 (high)

p-values of ANOVA and U test for usage variables and main usage factors. The entries in parentheses show if low or high prior domain knowledge / spatial ability led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.1.1.3.1 Use of the cell content

ANOVA for the usage variables “total time on cell”, “time on cross section of the cell” and “clicks on terms in cross section” revealed that prior domain knowledge had a significant impact on all three usage variables with low prior knowledge students using the cell content more intensively.

The results are presented in further detail in table 13 as well as in the figures 27 and 28.

Table 13 Cell – the impact of prior domain knowledge on content use

	low prior knowledge N = 116		high prior knowledge N = 110	
	M	SE	M	SE
total time on cell	489,5	20,8	440,7	20,1
time on cross section of the cell	448,3	19,2	387,4	18,8
clicks on terms in cross section	20,4	1,1	17,0	0,9

Impact of prior domain knowledge on the use of the cell content: time (seconds) and number of clicks.

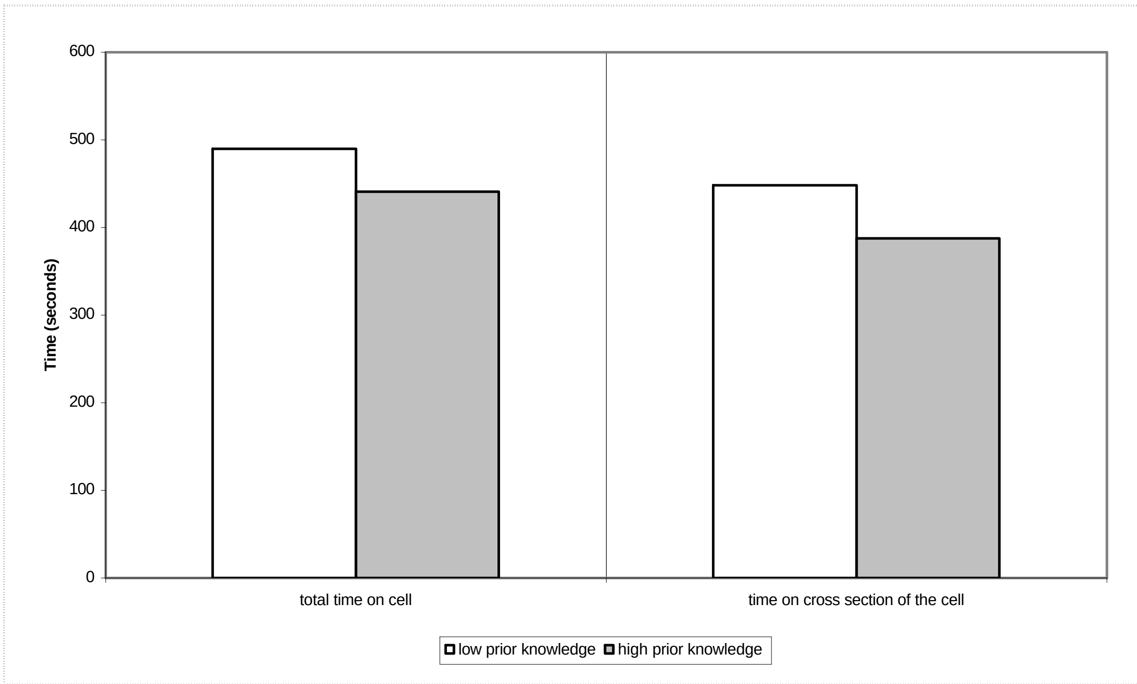

Figure 27 Cell - the impact of prior domain knowledge on content use (time)

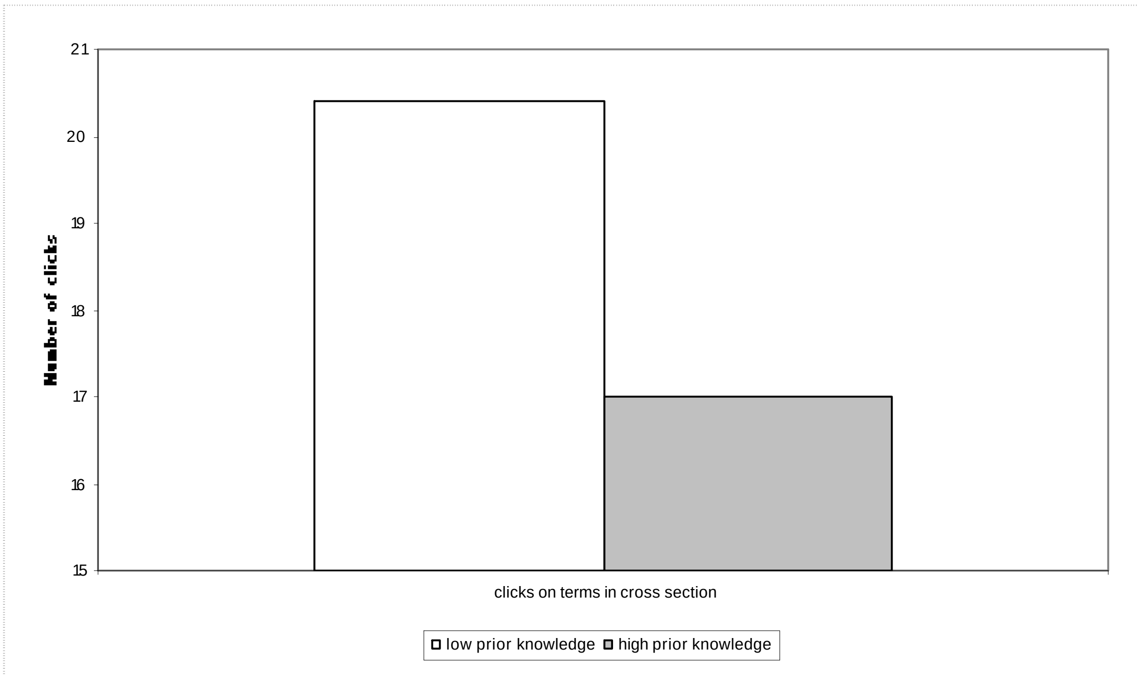

Figure 28 Cell - the impact of prior domain knowledge on content use (clicks)

No impact of spatial ability on total time (p=0,153) and use of cross section (p=0,103) but a significant influence on the number of clicks on the terms in the cross section (p=0,033) could be shown with high visual ability students using these terms more often (i.e. more clicks).
The results are presented in further detail in table 14 as well as in the figures 29 and 30.

Table 14 Cell – the impact of spatial ability on content use

	low spatial ability N = 114		high spatial ability N = 111	
	M	SE	M	SE
total time on cell	445,0	20,1	483,7	20,9
time on cross section of the cell	398,0	19,4	438,7	19,0
clicks on terms in cross section	17,3	1,1	20,3	1,0

Impact of spatial ability on the use of the cell content: time (seconds) and number of clicks.

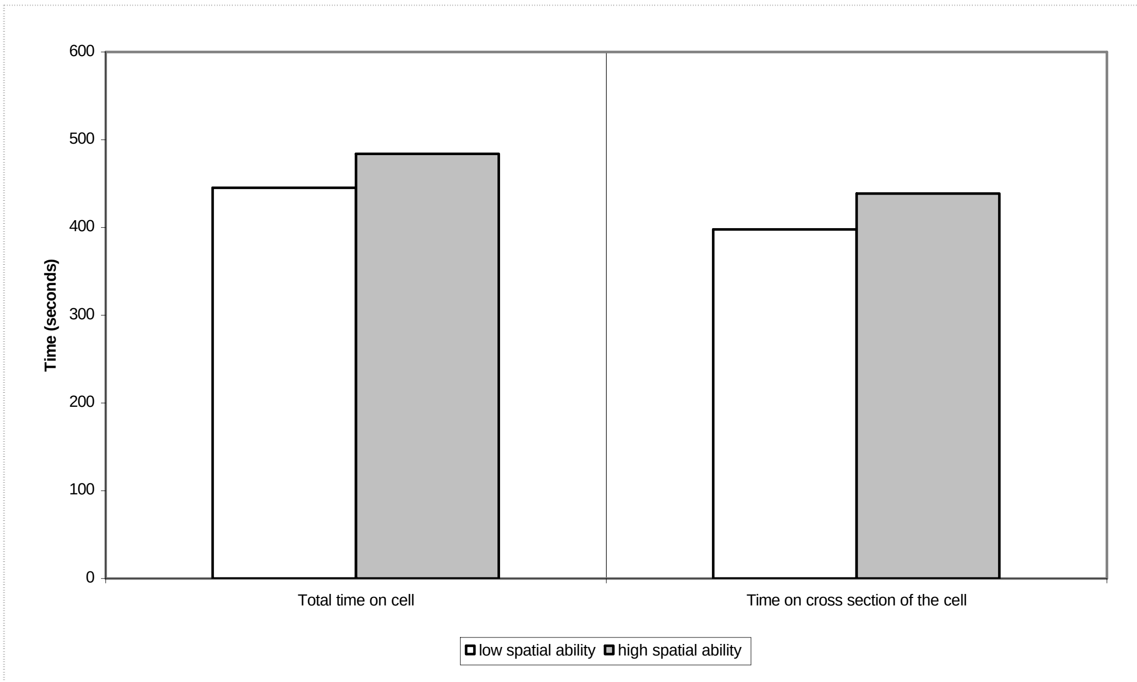

Figure 29 Cell – the impact of spatial ability on content use (time)

Figure 30 Cell – the impact of spatial ability on content use (clicks)

3.1.1.3.2 Navigation and use of learning support features / content collection

ANOVA showed that prior domain knowledge had a significant impact on the main usage factor “start of sitemap and use of back button” (p=0,038) with low prior knowledge students showing a more intensive use. Results of the U-test according to Mann and Whitney indicated an influencing trend of prior domain knowledge (p=0,067) on the main usage factor “start of explorative tour and use of back button and glossary”. Again students with low prior knowledge showed a more intensive use.

The results are presented in further detail in table 15 as well as in figure 31.

Table 15 Cell – the impact of prior domain knowledge on navigation/learning support

	low prior knowledge N = 116		high prior knowledge N = 110	
	M	SE	M	SE
start of sitemap and use of back button	*0,151*	*0,105*	*-0,109*	*0,084*
start of sitemap (st)	0,7	0,1	0,5	0,1
clicks on back button	7,5	0,8	5,4	0,5
start of explorative tour and use of back button and glossary	*0,141*	*0,105*	*-0,142*	*0,078*
start of explorative tour	1,2	0,1	1,1	0,1
clicks on glossary	1,9	0,4	1,6	0,4
clicks on back button	7,5	0,8	5,4	0,5

Impact of prior domain knowledge on navigation and the use of learning support features: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on the respective main usage factors.

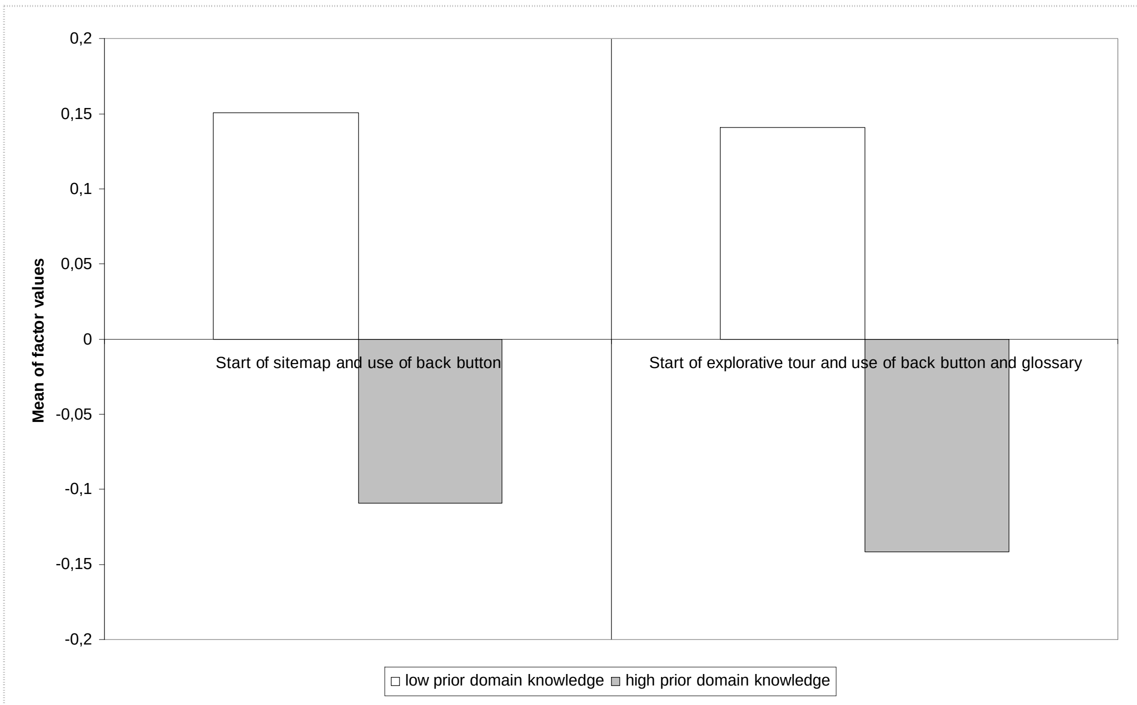

Figure 31 Cell – the impact of prior domain knowledge on navigation and the use of learning support features: factor values of the respective main usage factors.

Results of the U-test according to Mann and Whitney revealed a significant influence of spatial ability ($p = 0,029$) on the use of the audiovisual content collection of the CD-ROM. Students with low visual spatial ability showed a more intense use of these features than the high spatial ability group. Moreover, results of the U-test indicated an almost significant influence of spatial ability ($p=0,054$) on the use of notes and of pre-defined links. Students with high visual spatial ability used these features more intensively than students with low spatial ability.

The results are presented in further detail in table 16 as well as in figure 32.

Table 16 Cell – the impact of spatial ability on navigation/learning support/content collection

	low spatial ability N = 114		high spatial ability N = 111	
	M	SE	M	SE
use of audiovisual content collection	*0,060*	*0,126*	*-0,043*	*0,057*
time on cinema	24,1	7,4	13,4	3,8
time on 3D-models	15,8	4,7	13,1	3,1
control of films and animations	0,2	0,1	0,1	0,03
use of notes	*-0,033*	*0,097*	*0,068*	*0,099*
clicks on notes	0,4	0,1	0,6	0,1
time on open notes	15,0	6,1	15,8	5,3
use of pre-defined links	*-0,135*	*0,093*	*0,113*	*0,094*
clicks on link	0,2	0,04	0,4	0,06
clicks on button “one page up”	1,1	0,2	1,3	0,2

Impact of spatial ability on navigation and the use of learning support features and the audiovisual content collection: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading $\geq 0,5$ and $\leq - 0,5$ on the respective main usage factors.

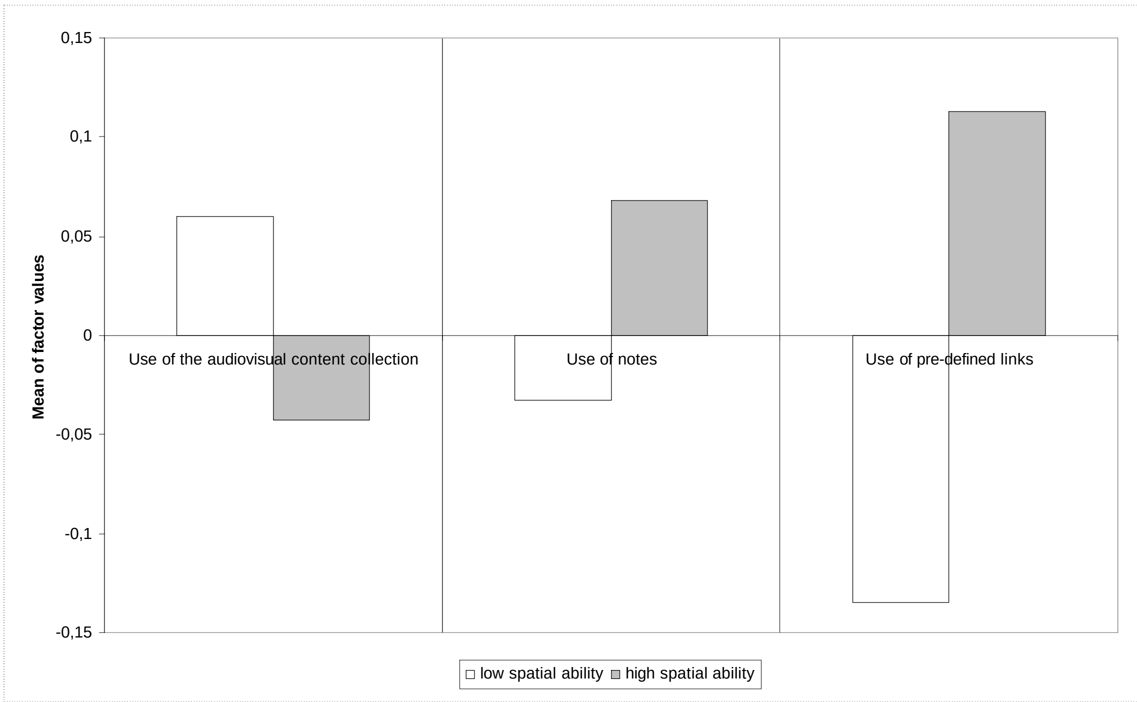

Figure 32 Cell – the impact of spatial ability on navigation as well as on the use of learning support features and the audiovisual content collection: factor values of the respective main usage factors.

3.1.1.4 Impact of learning style

The measured learning style dimensions are described in detail in the methods section 2.3.1.3. To get a satisfying reliability of the learning style questionnaire the analysis of this learner characteristic was carried out only with a sub-sample of examinees, namely the participants showing at least a moderate tendency of more than ± 5 for the respective learning style (leading to a Cronbach’s alpha of at least 0,7). Table 17 shows the number of students with respect to their learning style.

Table 17 Cell - learning style – distribution of students

LS	active	reflective	sensing	intuitive	sequential	global	visual	verbal
N	46	23	64	34	16	36	101	13

LS = learning style, N = number of students.

Table 18 provides an overview of the p-values for parametric and non-parametric statistics with the learning style serving as independent and the main usage factors as dependent variables.

Table 18 Cell – impact of learning style on hypermedia use – p-values

	Act/Ref	*Sen/Int*	*Seq/Glo*	*Vis/Ver*
total time on cell	0,428	0,458	0,358	0,418
time on cross section of the cell	0,541	0,299	0,405	0,527
clicks on terms in cross section	0,647	0,570	0,634	0,217
use of audiovisual content collection	0,236	0,507	0,383	0,204
use of quiz and quiz videos	0,098 (active)	0,028 (intuitive)	0,781	0,862
use of notes	0,959	0,107	0,812	0,446
use of sitemap (positive load on main usage factor)	0,017 (reflective)	0,643	0,373	0,924
Use of guided tour (negative load on main usage factor)	0,017 (active)	0,643	0,373	0,924
start of sitemap and use of back button	0,290	0,746	0,511	0,059 (visual)
start of explorative tour and use of back button and glossary	0,088 (reflective)	0,023 (intuitive)	0,526	0,501
use of pre-defined links	0,101	0,800	0,648	0,214

p-values of ANOVA and U test for usage variables and main usage factors. The entries in parentheses show which learning style (e.g. active or reflective) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.1.1.4.1 Use of the cell content

No impact of the different learning styles on the use of the cell content could be revealed.

3.1.1.4.2 Navigation and use of learning support features

ANOVAs with respect to the learning style act/ref showed a significant impact on the use of the sitemap or guided tour (p=0,017). Active learners were using the guided tour more intensively while reflective learners prefered to navigate with the sitemap.

Results of the U-test according to Mann and Whitney indicated an influence of the learning style act/ref on the use of quiz and videos (p=0,098) with active learners using them more intensively. Moreover, the test indicated an impact of this learning style on the main usage factor "start of the explorative tour and use of the back button and glossary" (p=0,088) with reflective learners showing a more intensive use.

The results are presented in further detail in table 19 as well as in figure 33.

Table 19 Cell – the impact of the learning style act/ref on navigation/learning support

	active N = 46		reflective N = 23	
	M	SE	M	SE
use of the sitemap or guided tour	*0,102*	*0,167*	*0,595*	*0,201*
start of sitemap (tt)	4,8	0,8	5,8	0,8
time on sitemap	43,8	5,2	52,9	7,9
start of guided tour	1,0	0,2	0,4	0,1
time on guided tour	189,1	39,5	60,5	25,1
use of quiz and quiz videos	*0,239*	*0,175*	*-0,135*	*0,163*
clicks on quiz	4,7	1,4	2,5	1,0
time on quiz videos	17,8	6,7	9,5	9,5
clicks on quiz videos	0,6	0,2	0,1	0,1
start of explorative tour and use of back button and glossary	*-0,070*	*0,132*	*0,401*	*0,245*
start of explorative tour	1,0	0,1	1,2	0,3
clicks on glossary	1,9	0,7	3,1	1,0
clicks on back button	5,7	0,9	5,5	1,4

Impact of learning style act/ref on navigation and the use of learning support features: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading $\geq$ 0,5 and $\leq$ - 0,5 on the respective main usage factors.

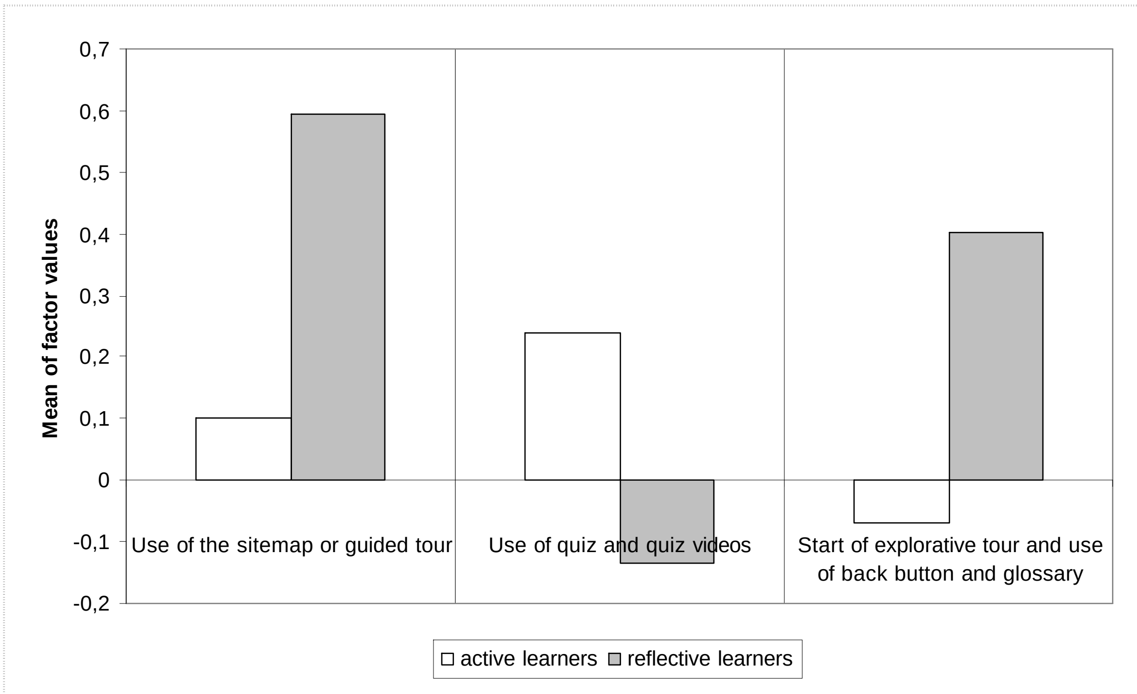

Figure 33 Cell – the impact of the learning style act/ref on navigation and the use of learning support features: factor values of the respective main usage factors.

Results of the U-test according to Mann and Whitney showed a significant influence of the learning style sen/int on the use of the quiz and quiz videos (p=0,028). Intuitive learners showed a more intensive use of the latter.

Also a significant impact of the learning style sen/int on the main usage factor “start of the explorative tour and use of the back button and glossary” (p=0,088) was revealed with intuitive learners showing a more intensive use.

The results are presented in further detail in table 20 as well as in figure 34.

Table 20 Cell –the impact of the learning style sen/int on navigation/learning support

	sensing N = 64		intuitive N = 34	
	M	SE	M	SE
use of quiz and quiz videos	*-0,053*	*0,127*	*0,472*	*0,251*
clicks on quiz	2,6	0,9	4,8	1,6
time on quiz videos	10,6	4,9	29,2	11,5
clicks on quiz videos	0,2	0,1	0,8	0,2
start of explorative tour and use of back button and glossary	*-0,108*	*0,119*	*0,246*	*0,134*
start of the explorative tour	1,0	0,1	1,5	0,2
clicks on glossary	1,8	0,5	1,6	0,5
clicks on back button	5,5	0,9	7,6	1,2

Impact of the learning style sen/int on navigation and the use of learning support features: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on the respective main usage factors.

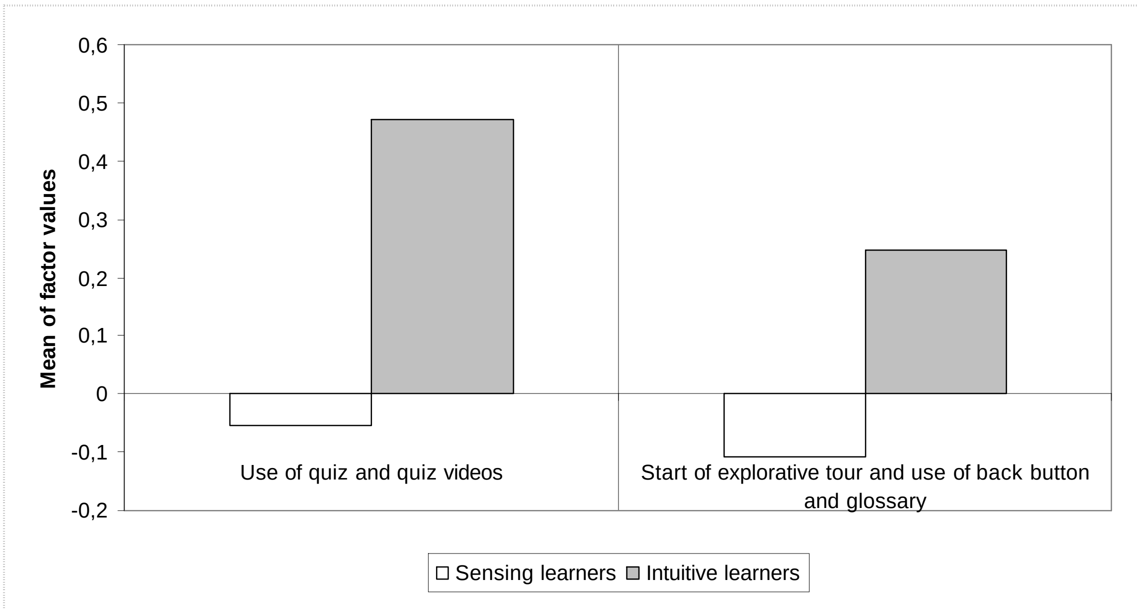

Figure 34 Cell – the impact of the learning style sen/int on navigation and the use of learning support features: factor values of the respective main usage factors.

ANOVAs with respect to the learning style vis/ver indicated an almost significant impact on the main usage factor “start of sitemap and use of back button” (p=0,059) with visual learners showing a more intensive use than verbal learners.
The results are presented in further detail in table 21 as well as in figure 35.

Table 21 Cell – the impact of the learning style vis/ver on navigation

	visual N = 101		verbal N = 13	
	M	SE	M	SE
start of sitemap and use of back button	*0,139*	*0,101*	*-0,507*	*0,198*
start of sitemap (st)	0,7	0,001	0,2	0,1
clicks on back button	6,9	0,7	5,1	1,6

Impact of the learning style vis/ver on navigation: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on the respective main usage factors.

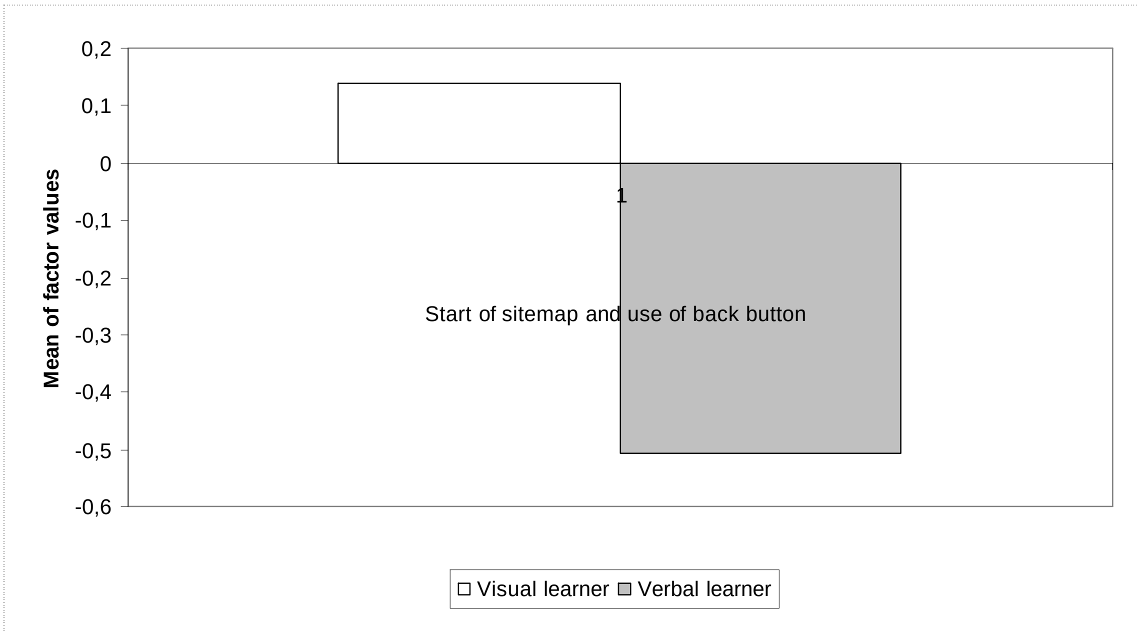

Figure 35 Cell – the impact of the learning style vis/ver on navigation: factor values of the respective main usage factor.

No impact of the learning style dimension “global / sequential” on navigation and the use of learning support features could be revealed.

3.1.2 Collaborative learning

In this chapter the results of students learning with the software in dyads, i.e. two students working jointly, are presented. The main usage factors resulting from the principle component analysis were further analyzed with respect to visual content representation. Due to the confounding influence of social interaction etc. (see above) in this context the learner characteristics were not investigated.

3.1.2.1 Main usage factors

9 main usage factors resulted from the principle component analysis. Table 22 shows the usage variables loading on the respective main usage factor. As described above, some variables load negatively.

Table 22 Cell – collaborative learning – main usage factors & variables

main usage factor	*variables (load strength in parentheses)*
use of cell content	time on cross section of the cell (0,97) total time on cell (0,93) clicks on terms in cross section (0,93)
use of audiovisual content collection	clicks on films and animations (0,87) time on 3D-lab (0,84)
use of quiz and quiz videos	time on quiz videos (0,95) clicks on quiz videos (0,95) clicks on quiz (0,63)
use of notes	time on open notes (0,95) clicks on notes (0,94)
use of sitemap or guided tour	Start of sitemap (tt) (0,87) time on sitemap (0,87) time on guided tour (-0,66) start of guided tour (- 0,58)
start of sitemap and use of back button	start of sitemap (st) (0,87) clicks on back button (0,83)
start of explorative tour	start of explorative tour (0,85)
use of index and menu	clicks on index (0,71) clicks on menu (0,66)
use of pre-defined links and glossary	clicks on link (0,80) clicks on one page up button (0,52) clicks on glossary (0,74)

Main usage factors and the usage variables loading on them ≥ 0,5 and ≤ -0,5.

The usage variable “time on cinema” was not loading with at least 0,5 on any of the main usage factors. It loaded maximally with 0,47 on the factor “use of index and menu”. No usage variable loaded with at least 0,5 on two or more main usage factors.

Normal and skewed distribution of the main usage factors

As mentioned above, the usage variables of the cell module and the main usage factors served in the further analysis as dependent variables. The Kolmogorov-Smirnov test showed a normal distribution of the usage variables “total time on cell”, “time on cross section of the cell” and “clicks on terms in cross section” as well as of the main usage factors “use of sitemap”, “use of index and menu” and “start of explorative tour”. Usage differences were calculated by means of ANOVAs.

All other main usage factors showed a skewed distribution. Accordingly, usage differences were calculated with H and U tests.

3.1.2.2 Impact of 3D-models, close-up-views and static picture design

The impact of visual content representation was investigated with a total of 92 student groups. Table 23 shows the distribution of the groups regarding the work with the different software variants.

Table 23 Cell – collaborative learning – content design - distribution of students to software variants

	software version			
	1	2	3	4
number of groups (N)	25	22	24	21

Table 24 provides an overview of the p-values of parametric and non-parametric statistics for the respective CD version as independent and the usage variables and main usage factors as dependent variables. If the result of the ANOVA or H test for all four CD-ROM versions showed a trend or a significant effect, a-priori contrasts or U tests were calculated for each software design parameter:

1) CD-ROM version 1/2: with/without 3D-models
2) CD-ROM version 2/3: with/without close-up-views
3) CD-ROM version 3/4: with a 3D-static or 2D-static picture of the cell’s cross section

Table 24 Cell – collaborative learning – impact of content design on hypermedia use – p-values

	CD 1-4	*CD 1/2: with/without 3D-models*	*CD 2/3: with/without close-up- views*	*CD 3/4: 3D/2D-static*
total time on cell	0,005	0,005 (with)	0,666	0,068 (2D-static)
time on cross section of the cell	0,156	-	-	-
clicks on terms in cross section	0,119	-	-	-
use of audiovisual content collection	0,853	-	-	-
use of quiz and quiz videos	0,560	-	-	-
use of notes	0,213	-	-	-
use of sitemap (positive load on main usage factor)	0,039	0,010 (with)	0,748	0,767
use of guided tour (negative load on main usage factor)	0,039	0,010 (without)	0,748	0,767
start of sitemap and use of back button	0,329	-	-	-
start of explorative tour	0,215	-	-	-
use of index and menu	0,223	-	-	-
use of pre-defined links and glossary	0,094	0,224	0,009 (with)	0,275

p-values of ANOVA (a-priori contrast for single CD versions) and H test (U test for single CD versions) for the usage variables and main usage factors. The entries in parentheses show which design feature (e.g. with or without 3D-models) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.1.2.2.1 Use of the cell content

Analysing the use of the four software versions, ANOVAs showed a highly significant difference regarding the total time spent on the content module “cell” (p=0,005). This can be attributed mainly to a different use of the CD versions 1/2 with/without 3D-models: students using the version with 3D-models (a-priori contrasts p=0,005) spent more time on the content module “cell”. Moreover, a trend pointing to a different use of the versions 3/4 with 3D/2D-static pictures could be revealed (a-priori contrasts, p=0,068) with students using the 2D-version to spend more time on the content module.

The results are presented in further detail in table 25 as well as in figure 36.

Table 25 Cell – collaborative learning – the impact of content design on content use

	CD version 1		CD version 2		CD version 3		CD version 4	
	N = 25		N = 22		N = 24		N = 21	
	M	SE	M	SE	M	SE	M	SE
total time on cell	556,9	42,5	384,6	45,9	358,2	31,2	471,9	52,3
time on cross section of the cell	344,5	38,6	384,6	45,9	358,2	31,2	471,9	52,3
clicks on terms in cross section	12,7	1,8	14,4	1,8	14,6	1,4	18,9	2,4

Impact of content design on the use of cell content: time (seconds) and number of clicks.

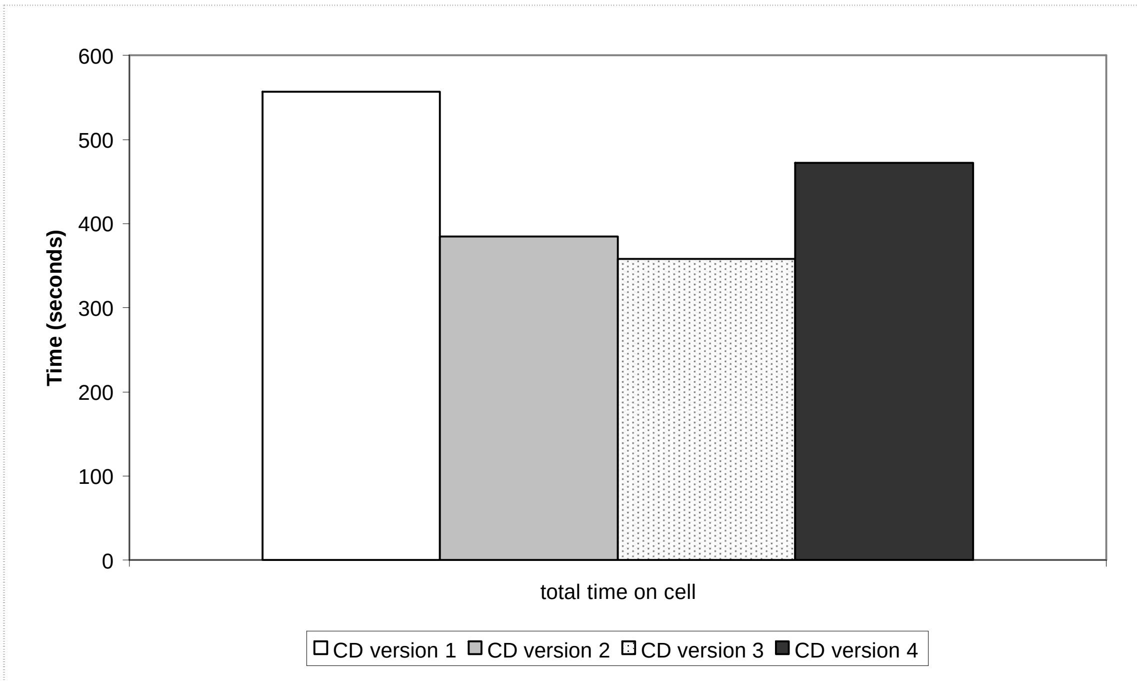

Figure 36 Cell – collaborative learning – the impact of content design on content use (time)

3.1.2.2.2 Navigation and use of learning support features

ANOVAs revealed a significant difference between the single software versions in the usage of the sitemap or guided tour (p=0,039). This finding was mainly based on a different use of the version 1/2 "with/without 3D-models" (a-priori contrast, p=0,010). Students working with the version including 3D-models used the sitemap more and the guided tour less intensively than students with the variant that did not contain 3D-models. No difference in the use of the other versions (“with/without close-up-views”, a-priori contrast, p=0,748; “3D-static/2D-static”, a-priori contrast, p=0,767) could be found.

The H-test according to Kruskal and Wallis revealed a trend pointing to a difference in the use of the glossary and pre-defined links between the four CD versions (p=0,094). Subsequent Mann-Whitney U tests showed that this difference was based on a highly significant difference in use between the software versions 2/3 with and without close-up-views (p=0,009). Working with the variant including close-up-views the use of these features was much higher. Results were not significant for the version “with/without 3D-models” (p=0,224) and “3D-static/2D-static pictures” (p=0,275).

The results are presented in further detail in table 26 as well as in figure 37.

Table 26 Cell – collaborative learning – the impact of content design on navigation/learning support

	CD version 1		CD version 2		CD version 3		CD version 4	
	N = 25		N = 22		N = 24		N = 21	
	M	SE	M	SE	M	SE	M	SE
use of site map or guided tour	*0,479*	*0,227*	*-0,268*	*0,192*	*-0,176*	*0,176*	*-0,089*	*0,205*
start of sitemap	4,1	0,7	3,2	0,7	2,8	0,5	3,2	0,8
time on sitemap	47,3	6,9	33,8	5,3	40,1	5,9	33,4	5,8
start of guided tour	1,0	0,4	1,6	0,4	1,4	0,2	1,4	0,3
time on guided tour	123,6	47,1	313,5	78,0	288,6	71,8	178,9	48,7
use of pre-defined links and glossary	*-0,004*	*0,154*	*0,203*	*0,182*	*-0,247*	*0,213*	*0,075*	*0,284*
clicks on link	0,3	0,1	0,6	0,1	0,3	0,1	0,5	0,2
clicks on “one page up” button	0,7	0,3	0,9	0,4	0,7	0,3	0,9	0,3
clicks on glossary	1,6	0,6	1,3	0,5	1,1	0,3	2,0	0,7

Impact of content design on navigation and the use of learning support features: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on the respective main usage factors.

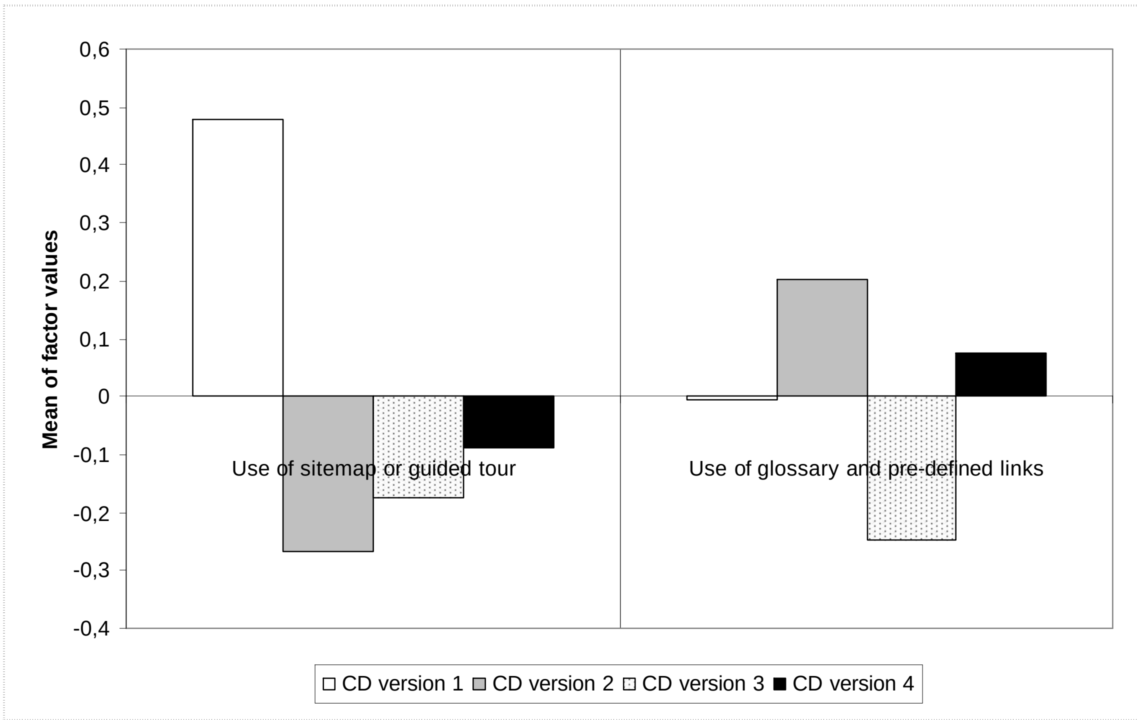

Figure 37 Cell – collaborative learning – the impact of content design on navigation and the use of learning support features: factor values of the respective main usage factors.

3.1.3 Summary of results – module “plant and animal cell”

The results are summarized in two sections: one dealing with

- the impact of software design; the other with
- the impact of learner characteristics.

3.1.3.1 Impact of 3D-models, close-up-views and static picture design

3.1.3.1.1 Individual learning

In the individual learning situation the results of parametric and non-parametric statistics revealed different impacts of the content design variants on hypermedia use:

a) use of the cell content
   - the presence of 3D models and the absence of close-up-views led to a longer usage time of the content module “cell”
   - moreover, the absence of close-up-views led to a higher frequency of clicks on technical terms of the cell’s cross section

b) navigation and use of learning support features
   - the presence of 3D models led to a more intensive use of the sitemap, their absence on the other hand to a more intensive use of the guided tour
   - the opposite effect was observed for close-up-views: their absence led to a more intensive use of the sitemap, their presence to that of the guided tour
   - moreover, it could be shown that decreasing visual details of the content presentation led to an increasing use of quiz and quiz videos.

The results are summarized in table 27.

Table 27 Cell – summary of results - individual learning – impact of content design on hypermedia use

	with/without 3D-models	*with/without close-up- views*	*3D/2D-static design of the cross section*
total time on cell	with	without	
clicks on terms in cross section		without	
use of sitemap	with	without	
use of guided tour	without	with	

Dependent variables of hypermedia use that were influenced by the content design. The entries show which design feature (e.g. with or without 3D-models) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.1.3.1.2 Collaborative learning

In the collaborative learning situation the results of parametric and non-parametric statistics also showed different impacts of the investigated content design variants on hypermedia use:

a) use of the cell content
   - the presence of 3D models led to a longer usage time of the content module "cell"
   - a 2D-static design of the cell's cross section also led to a longer usage time of the content module "cell"

b) navigation and use of learning support features
   - the presence of 3D models led to a more intensive use of the sitemap, their absence to a more intensive use of the guided tour
   - the presence of close-up-views led to a more intensive use of pre-defined links and the glossary.

The results are summarized in table 28.

Table 28 Cell – summary of results - collaborative learning – impact of content design on hypermedia use

	with/without 3D-models	*with/without close-up-views*	*3D/2D-static design of the cross section*
total time on cell	with		2D-static
use of sitemap	with		
use of guided tour	without		
use of pre-defined links and glossary		with	

Dependent variables of hypermedia use that were influenced by the content design. The entries show which design feature (e.g. with or without 3D-models) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.1.3.2 Impact of learner characteristics

In the individual learning situation the results of parametric and non-parametric statistics showed different impacts of prior domain knowledge, spatial ability and learning style on hypermedia use:

a) use of the cell content

   - low prior domain knowledge led to a longer usage time of the content module on the whole as well as of the cell’s cross section. Moreover, a higher frequency of clicks on technical terms in the cross section could be revealed
   - high spatial ability led to a higher frequency of clicks on technical terms in the cross section

b) navigation and use of learning support features / content collection

   - low prior domain knowledge led to a more pronounced tendency to start with the sitemap or explorative tour as well as to use the back button and the glossary
   - low spatial ability led to a more intensive use of the audiovisual content collection of the CD ROM, high spatial ability to a more intensive use of notes and of pre-defined links
   - the active learning style led to a more intensive use of quiz and quiz videos and a preference for the guided tour, the reflective learning style to a preference for the sitemap and explorative tour and to a more intensive use of the glossary
   - the intuitive learning style led to a more intensive use of the quiz and quiz videos and a more pronounced tendency to start with the explorative tour and to navigate with the back button
   - the visual learning style led to a more pronounced tendency to start with the sitemap and to use the back button.

For details see tables 29 and 30 below.

Table 29 Cell – summary of results – impact of prior knowledge / spatial ability on hypermedia use

	Prior domain knowledge	*Spatial ability*
total time on cell	low	
time on cross section of the cell	low	
clicks on terms in cross section	low	high
use of audiovisual content collection		low
use of notes		high
start of sitemap and use of back button	low	
start of explorative tour and use of back button and glossary	low	
use of pre-defined links		high

Dependent variables of hypermedia use that were influenced by learner characteristics. The entries show if a low or high prior domain knowledge / spatial ability led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

Table 30 Cell – summary of results – the impact of learning style on hypermedia use

	Act/Ref	*Sen/Int*	*Seq/Glo*	*Vis/Ver*
use of quiz and quiz videos	active	intuitive		
use of sitemap	reflective			
use of guided tour	active			
start of sitemap and use of back button				visual
start of explorative tour and use of back button and glossary	reflective	intuitive		

Dependent variables of hypermedia use that were influenced by learner characteristics. The entries show which learning style (e.g. active or reflective) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.2 Module “ATP synthase”

3.2.1 Individual learning

In this chapter the results of students learning individually with the software are presented. The main usage factors resulting from the principle component analysis were further analyzed with respect to the impact of animation design, i.e. 3D/2D-design and presence/absence of signals as well as with respect to the learner characteristics prior domain knowledge, spatial ability and learning style.

3.2.1.1 Main usage factors

11 main usage factors resulted from the principle component analysis. Table 31 shows the usage variables loading on the respective usage factor. As described above one usage variable loads negatively.

Table 31 ATP – individual learning – main usage factors & variables

main usage factor	*variables (load strength in parentheses)*
use of ATP content module	time on animation ATP 1-4 (0,92) time on content module ATP (0,54)
use of single ATP animation sequences	time on sequence ATP 1 (0,80) time on sequence ATP 2 (0,87) time on sequence ATP 3 (0,87) time on sequence ATP 4 (0,82) time on content module ATP (0,67)
use of audiovisual content collection	control of films and animations (0,80) time on 3D-lab (0,73)
use of films and menu	time on cinema (0,80) clicks on menu (0,55)
use of quiz and quiz videos	clicks on quiz videos (0,91) time on quiz videos (0,85) clicks on quiz (0,65)
use of notes	time of open notes (0,89) clicks on notes (0,85)
use of guided tour	start of guided tour (0,89) time on guided tour (0,85)
use of sitemap	time on sitemap (0,76) start of sitemap (tt) (0,62)
use of back and one-page-up button	clicks on back button (0,84) clicks on one page up button (0,61)
start of sitemap or explorative tour	start of explorative tour (0,84) start of sitemap (st) (-0,80)
use of glossary and pre-defined links	clicks on glossary (0,71) clicks on link (0,63)

Main usage factors and the usage variables loading on them ≥ 0,5 and ≤ -0,5.

Not loading with at least 0,5 on a main usage factor were the usage variables

- "control of ATP animation" (max. on "use of glossary and pre-defined links" with 0,35), and
- "clicks on index" (max. on "use of back and one-page-up button" with 0,24).

The usage variable “time on content module ATP” was loading on two main usage factors with at least 0,5:

- “use of ATP content module” (0,54), and
- “use of single ATP animation sequences” (0,67).

This variable was therefore taken into consideration to interpret both factors.

Normal and skewed distribution of main usage factors

The resulting main usage factors served in the further analysis as dependent variables. Kolmogorov-Smirnov test showed a normal distribution only of the usage variable “time on content module ATP” and the main usage factor “use of sitemap”. These factors were calculated with respect to usage differences by means of ANOVAs. The other usage variables “time on animation ATP 1-4” and “control of ATP animation” as well as all other main usage factors showed a skewed distribution. Accordingly, usage differences were calculated with U tests.

3.2.1.2 Impact of animation design

The analysis of the impact of animation design was carried out with a total of 267 students. Table 32 shows the distribution of the students regarding their work with the different software versions.

Table 32 ATP – animation design – distribution of the students to the software variants

software version			
3D-dynamic	2D-dynamic	with signals	without signals
N=137	N=130	N=142	N=125

Table 33 provides an overview of the p-values of parametric and non-parametric statistics for the animation design (3D/2D and with/without signals) as independent and the usage variables and main usage factors as dependent variables.

Table 33 ATP – individual learning – the impact of animation design on hypermedia use – p-values

	3D-dynamic/2D-dynamic	*with/without signals*
time on content module ATP	0,402	0,039 (with)
time on animation sequences ATP 1-4	0,763	0,682
control of ATP animation	0,020 (3D-dynamic)	0,036 (without)
use of single ATP animation sequences	0,633	0,179
use of audiovisual content collection	0,626	0,746
use of films and menu	0,788	0,358
use of quiz and quiz videos	0,016 (2D-dynamic)	0,900
use of notes	0,688	0,417
use of guided tour	0,027 (2D-dynamic)	0,899
use of sitemap	0,367	0,471
use of back and one-page-up button	0,021 (2D-dynamic)	0,598
start of sitemap or explorative tour	0,591	0,750
use of glossary and pre-defined links	0,072 (3D-dynamic)	0,834

p-values of ANOVAs and U tests for all usage variables and main usage factors. The entries in parentheses show which design feature (e.g. with or without signals) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.2.1.2.1 Use of the ATP content

U-tests investigating the impact of animation design showed a significant difference regarding the control of the ATP animation with respect to both design parameters "3D/2D-dynamic animation design" (p=0,020) as well as "with/without signals" (p=0,036). There was more active control of the animation when it was designed in a three-dimensional way or without signals. Moreover results of the ANOVA showed a significant impact of the CD version "with/ without signals" (p=0,039) on the total time students were using the ATP content module: namely, students using the version with signals spent significantly more time with the animation.

The results are presented in further detail in the tables 34 and 35 as well as in the figures 38, 39 and 40.

Table 34 ATP – individual learning – the impact of 3D/2D-dynamic animation design on content use

	3D-dynamic N = 137		2D-dynamic N = 130	
	M	SE	M	SE
control of ATP animation	1,5	0,3	0,6	0,2

Impact of the 3D/2D-dynamic design on the control of the ATP content module: number of clicks.

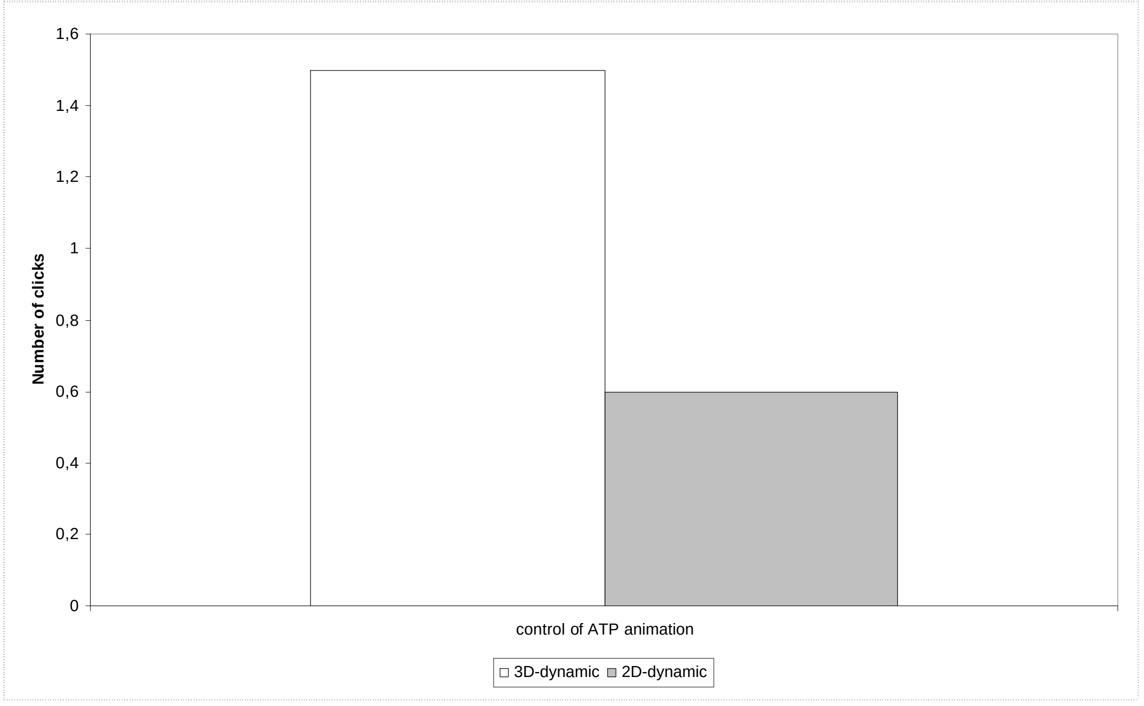

Figure 38 ATP – individual learning – the impact of 3D/2D-dynamic animation design on the control of the ATP content module: number of clicks.

Table 35 ATP – individual learning – the impact of the presence/absence of signals on content use

	with signals N = 142		without signals N = 125	
	M	SE	M	SE
control of ATP animation	0,9	0,2	1,2	0,2
time on content module ATP	645,1	21,9	582,0	21,5

Impact of the presence/absence of signals on the control (number of clicks) of the ATP animation and time (seconds) on the content module ATP.

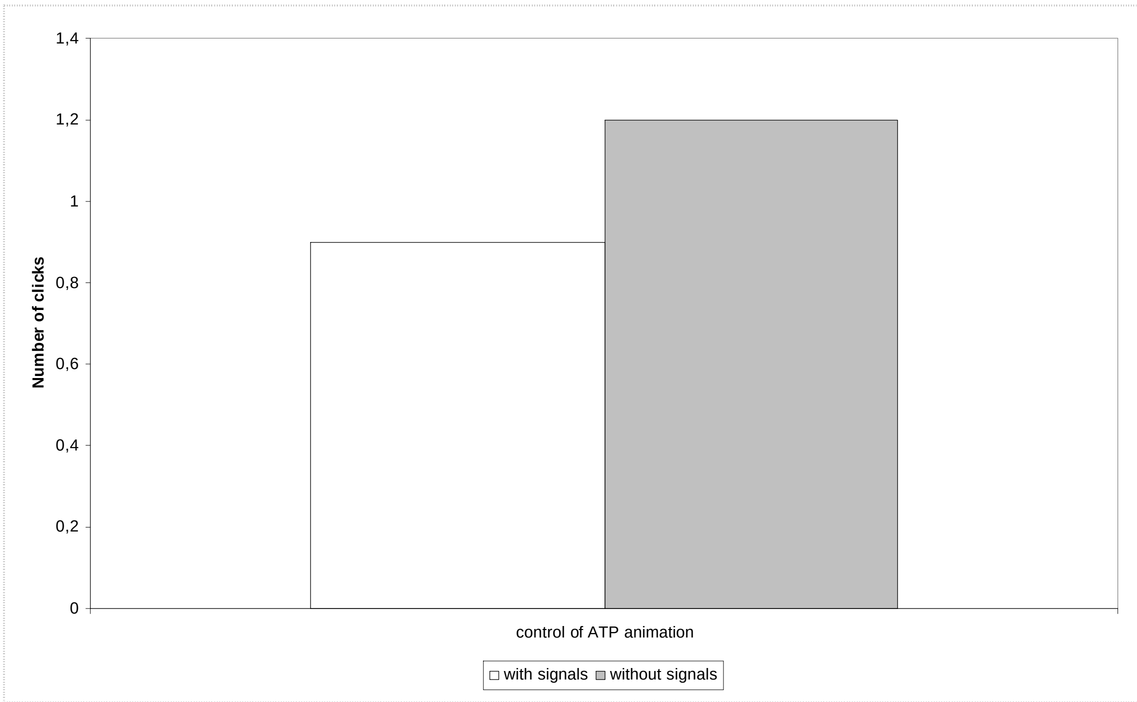

Figure 39 ATP – individual learning – the impact of the presence/absence of signals on the control (number of clicks) of the ATP animation.

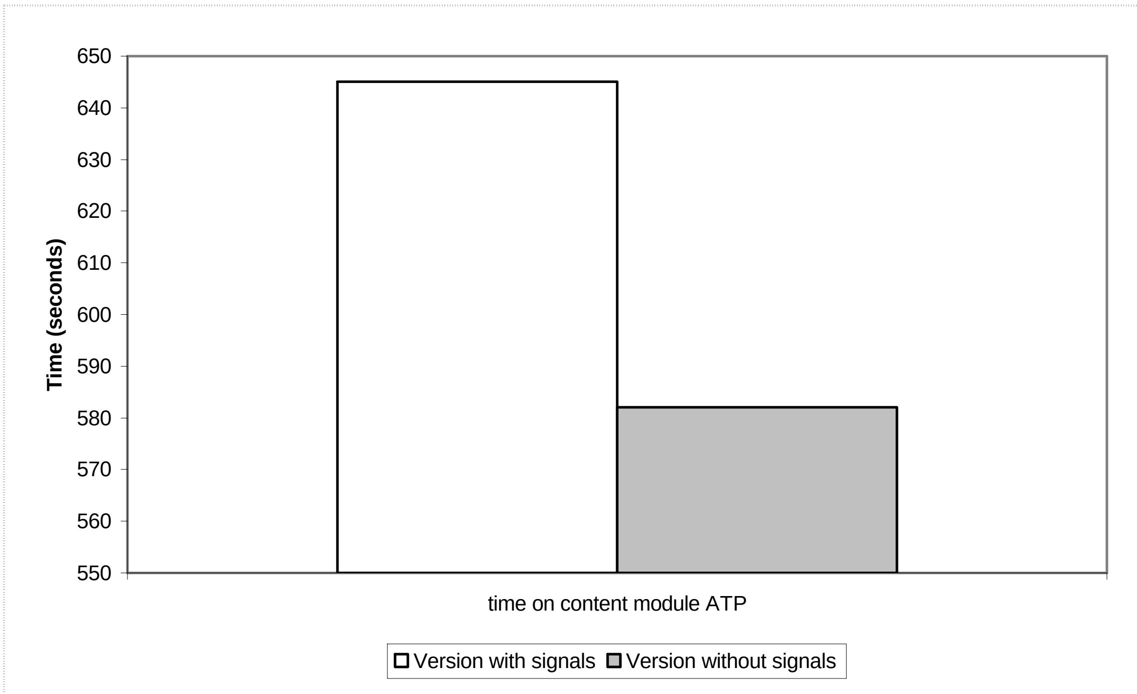

Figure 40 ATP – individual learning – the impact of the presence/absence of signals on the time (seconds) users spent on the content module ATP.

3.2.1.2.2 Navigation and use of learning support features

The U-test according to Mann and Whitney showed a significant difference in the use of quiz and quiz videos (p=0,016), the guided tour (p=0,027) and the clicks on the back and one-page up buttons (p=0,021) with respect to the parameter “3D/2D-dynamic animation design”. There was a significantly more intensive use of these features when the animation of the content module ATP was designed in a two-dimensional way. Results of the U-test indicated an influence of the CD version “3D/2D-dynamic (p=0,072) on the use of the glossary and the pre-defined links. In case of the latter participants using the 3D-version showed a more intensive use.

No impact of the presence/absence of signals on the use of navigation and learning support features could be revealed.

The results are presented in further detail in table 36 as well as in figure 41.

Table 36 ATP – individual learning – the impact of 3D/2D dynamic animation design on navigation/learning support

	3D-dynamic N = 137		2D-dynamic N = 130	
	M	SE	M	SE
use of quiz and quiz videos	*-0,141*	*0,069*	*0,148*	*0,101*
clicks on quiz	3,9	0,8	7,2	1,1
time on quiz video	15,9	4,8	25,2	6,8
clicks on quiz video	0,5	0,1	0,9	0,2
use of the guided tour	*-0,112*	*0,074*	*0,118*	*0,098*
start of guided tour	0,4	0,1	0,7	0,1
time on guided tour	65,3	17,1	70,6	18,5
use of back and one-page-up button	*-0,147*	*0,074*	*0,155*	*0,097*
clicks on back button	2,5	0,4	4,9	0,8
clicks on one page up button	0,8	0,2	1,1	0,2
use of glossary and pre-defined links	*0,118*	*0,094*	*-0,124*	*0,076*
clicks on glossary	2,1	0,3	1,5	0,3
clicks on link	0,3	0,1	0,3	0,1

Impact of the 3D/2D-dynamic design of the ATP animation on navigation and the use of learning support features: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on the respective main usage factors.

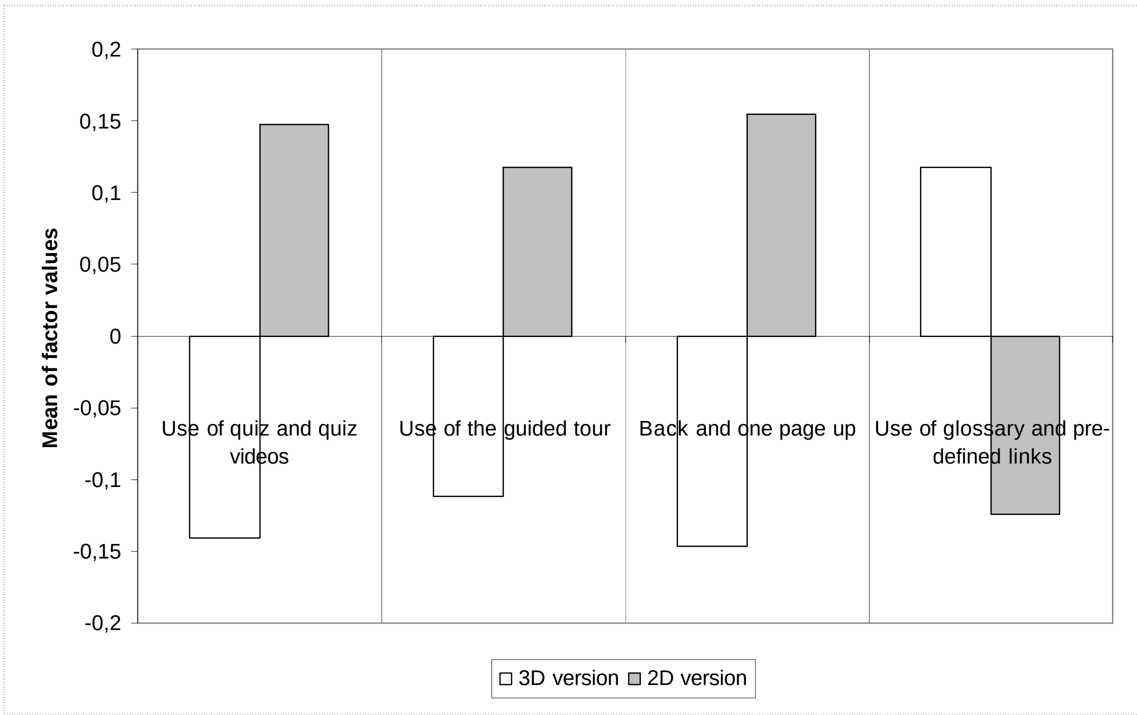

Figure 41 ATP – individual learning – the impact of 3D/2D dynamic animation design on navigation and the use of learning support features: factor values of the respective main usage factors.

3.2.1.3 Impact of prior domain knowledge and spatial ability

The impact of prior knowledge was investigated with 245 students, the impact of spatial ability with 244 individuals. Median split classified participants as possessing low or high prior domain knowledge/spatial ability. Table 37 shows the distribution of the students to the different groups.

Table 37 ATP – prior knowledge / spatial ability – distribution of students

Prior domain knowledge		Spatial ability	
low	high	low	high
N=127	N=118	N=127	N=117

Table 38 provides an overview of the p-values for parametric and non-parametric statistics regarding prior domain knowledge and spatial ability as independent and the usage variables and main usage factors as dependent variables.

Table 38 ATP – the impact of prior knowledge / spatial ability on hypermedia use – p-values

	Prior domain knowledge	*Spatial ability*
time on content module ATP	0,002 (low)	0,177
time on animation sequences ATP 1-4	0,069 (low)	0,660
control of ATP animation	0,417	0,424
use of single ATP animation sequences	0,038 (low)	0,048 (low)
use of audiovisual content collection	0,435	0,688
use of films and menu	0,041 (high)	0,313
use of quiz and quiz videos	0,911	0,129
use of notes	0,001 (low)	0,113
use of guided tour	0,665	0,844
use of sitemap	0,224	0,371
use of back and one-page-up button	0,201	0,371
start of explorative tour (positive load on main usage factor)	0,737	0,065 (low)
start of sitemap (negative load on main usage factor)	0,737	0,065 (high)
use of glossary and pre-defined links	0,857	0,542

p-values of ANOVA and U test for usage variables and main usage factors. The entries in parentheses show if a low or high prior domain knowledge / spatial ability led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.2.1.3.1 Use of the ATP content

Results of the ANOVA showed a significant impact of prior domain knowledge on the time users spent on the content module ATP (p=0,002). The U-test according to Mann and Whitney showed an impact on the use of the ATP animation sequences 1-4 (p=0,069) but no difference in the active control of the ATP animation (p=0,417). Users with low prior domain knowledge spent more time on the content module and the animation sequences 1-4. Moreover, a significant influence of prior domain knowledge on the use of the four single sequences of the ATP content module could be shown (p=0,038) with students of low prior knowledge using the ATP sequences more intensively than the group with high prior domain knowledge.

The results are presented in further detail in table 39 as well as in figure 42 and 43.

Table 39 ATP – the impact of prior domain knowledge on content use

	low prior knowledge N = 127		high prior knowledge N = 118	
	M	SE	M	SE
time on content module ATP	655,6	23,2	556,5	21,0
time on animation sequences ATP 1-4	107,0	15,2	65,2	10,4
use of single ATP animation sequences	*0,116*	*0,093*	*-0,138*	*0,084*
time on sequence ATP 1	62,2	6,1	36,2	4,4
time on sequence ATP 2	46,4	5,0	34,2	3,9
time on sequence ATP 3	36,1	4,0	31,2	3,5
time on sequence ATP 4	92,1	9,2	80,0	8,5

Impact of prior domain knowledge on the time (seconds) users spent on the content module ATP and the single sequences of the animation; factor values of main usage factor "use of single ATP animation sequences" (*italics*).

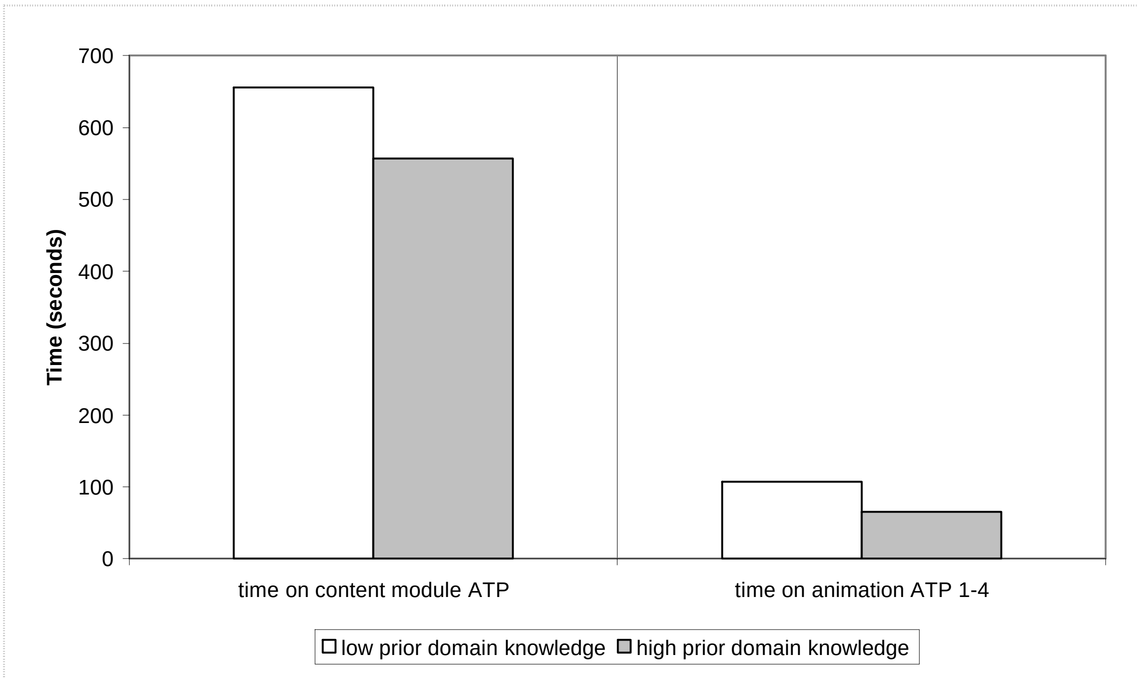

Figure 42 ATP – the impact of prior domain knowledge on the time (seconds) users spent on the content module ATP and the single sequences of the animation.

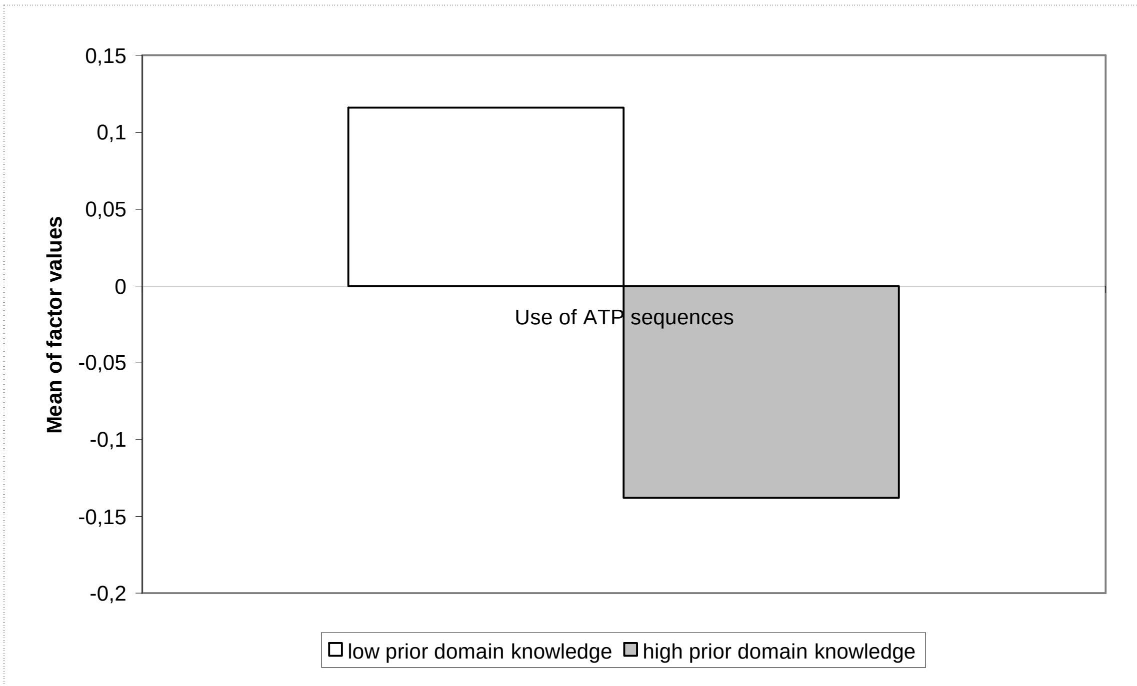

Figure 43 ATP – the impact of prior domain knowledge on the time users spent on the single sequences of the animation: factor values of the respective main usage factor.

Results of the U-test according to Mann and Whitney showed a significant influence of spatial ability (p=0,048) on the use of the four single sequences of the ATP content module. Students with little visual spatial ability showed a more intensive use of the ATP sequences than the group with high spatial ability.

The results are presented in further detail in table 40 as well as in figure 44.

Table 40 ATP –the impact of spatial ability on content use

	low spatial ability N = 127		high spatial ability N = 117	
	M	SE	M	SE
use of single ATP animation sequences	*0,054*	*0,084*	*-0,088*	*0,095*
time on content module ATP	626,6	22,7	583,3	22,4
time on sequence ATP 1	51,0	4,9	47,3	6,2
time on sequence ATP 2	42,8	4,2	37,4	4,8
time on sequence ATP 3	34,2	3,7	32,5	3,9
time on sequence ATP 4	88,4	8,4	81,4	9,1

Impact of spatial ability on the use of the ATP animation sequences: factor values of main usage factor (italics); time (seconds) of the usage variables loading ≥ 0,5 on this factor.

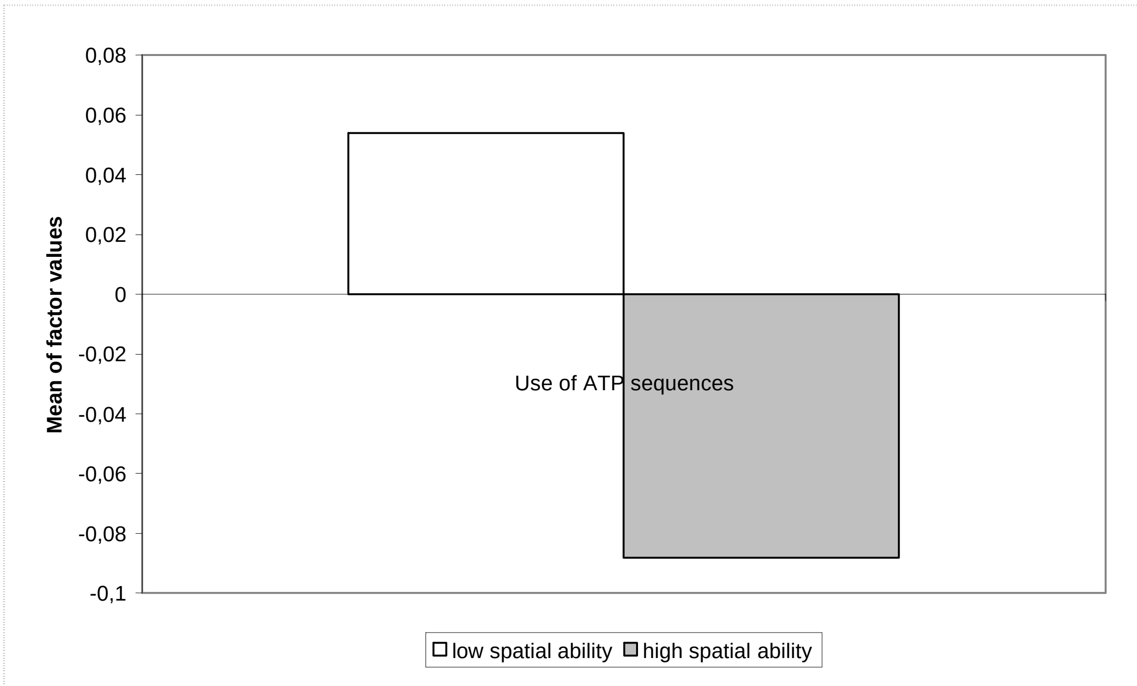

Figure 44 ATP – the impact of spatial ability on the time users spent on the single sequences of the animation: factor values of the respective main usage factor.

3.2.1.3.2 Navigation and use of learning support features

Results of the U-test according to Mann and Whitney showed a significant impact of prior domain knowledge (p=0,041) on the use of films and the menu. Namely, participants with a high prior knowledge used these features more intensively. Moreover, the U-test results indicated a highly significant influence of prior knowledge (p<0,001) on the use of notes. Students with low prior knowledge used the notes more intensively than students with high prior knowledge.

The results are presented in further detail in table 41 as well as in figure 45.

Table 41 ATP – the impact of prior domain knowledge on navigation/learning support

	low prior knowledge N = 127		high prior knowledge N = 118	
	M	SE	M	SE
use of films and menu	*-0,839*	*0,084*	*0,118*	*0,100*
time on cinema (all films)	14,5	5,2	19,6	6,2
clicks on menu	0,9	0,1	1,1	0,1
use of notes	*0,243*	*0,112*	*-0,183*	*0,057*
clicks on notes	0,6	0,1	0,2	0,05
time on open notes	48,9	13,1	12,8	9,9

Impact of prior domain knowledge on navigation and the use of learning support features: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on the respective main usage factors.

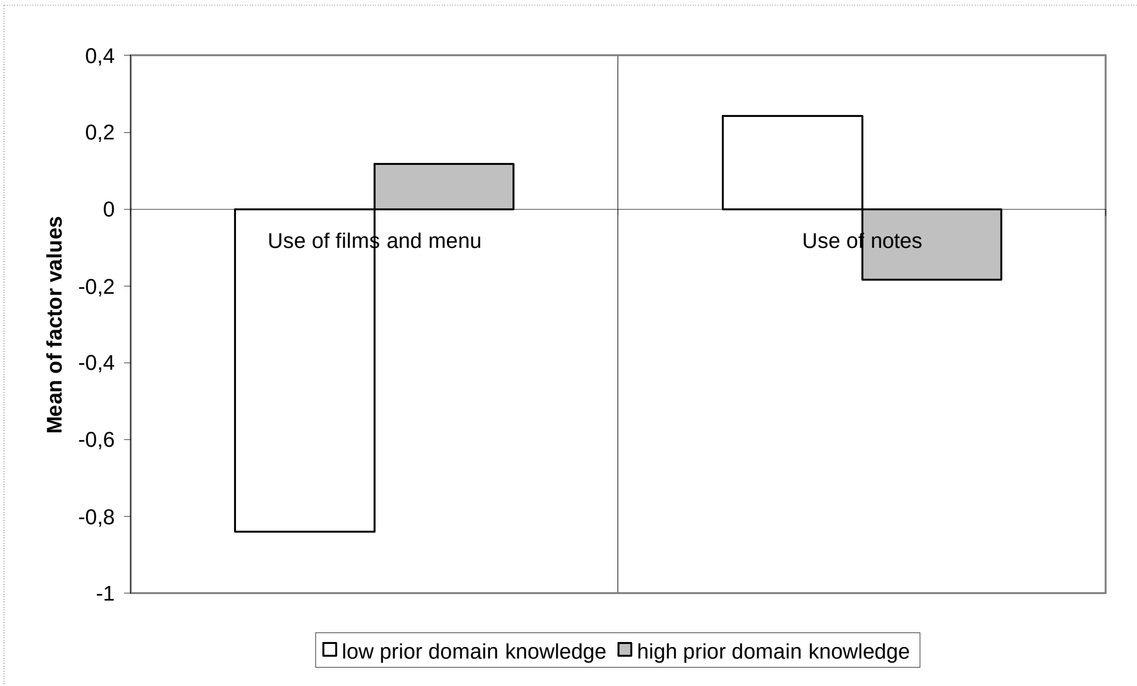

Figure 45 ATP – the impact of prior domain knowledge on navigation and the use of films and learning support features: factor values of the respective main usage factors.

Results of the U-test according to Mann and Whitney showed a trend regarding an influence of spatial ability on the main usage factor "start of explorative tour or sitemap" (p=0,065). Students with low visual spatial ability showed a higher preference to start with the explorative tour whereas the group with high spatial ability preferred to start with the sitemap. The results are presented in further detail in table 42 as well as in figure 46.

Table 42 ATP – the impact of spatial ability on navigation

	low spatial ability		high spatial ability	
	N = 127		N = 117	
	M	SE	M	SE
start of explorative tour or sitemap	*0,086*	*0,092*	*-0,127*	*0,090*
start of explorative tour	0,7	0,1	0,5	0,1
start of sitemap (st)	0,7	0,1	0,8	0,1

Impact of spatial ability on navigation: factor values of main usage factors (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on the respective main usage factors.

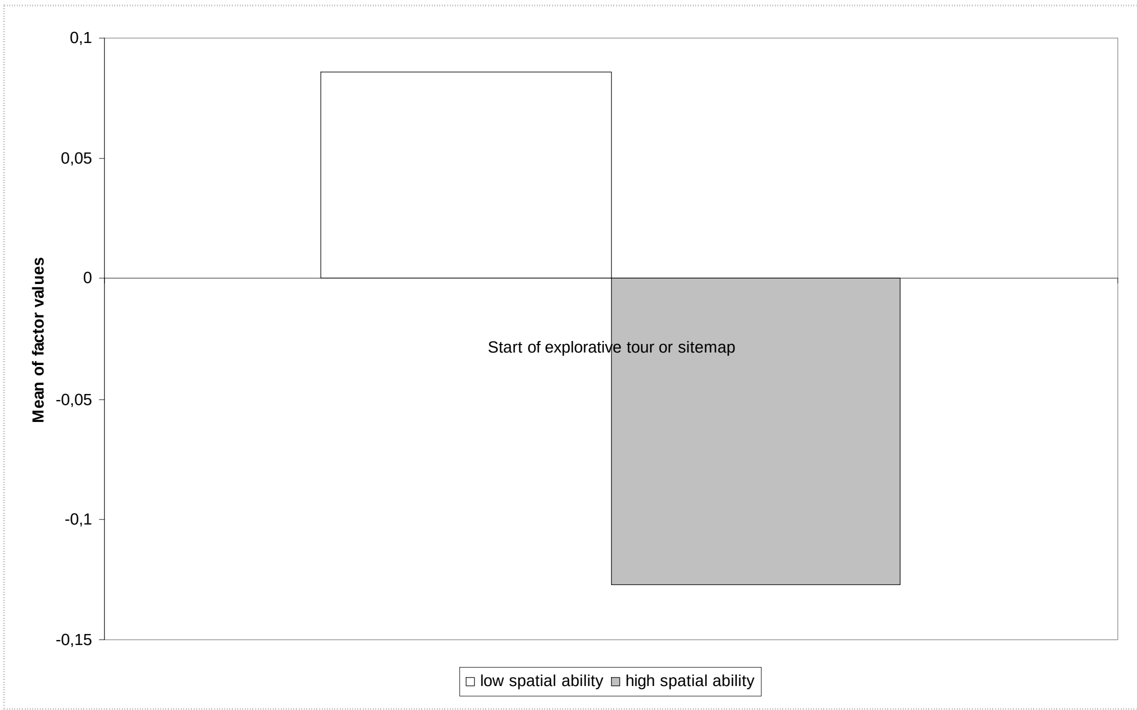

Figure 46 ATP – the impact of spatial ability on navigation: factor values of the respective main usage factor.

3.2.1.4 Impact of learning style

The measured learning style dimensions are described in detail in the methods section 2.3.1.3. To get a satisfying reliability of the learning style questionnaire the analysis of this learner characteristic was carried out only with a sub-sample of examinees, namely the participants showing at least the moderate tendency of more than ± 5 (leading to a Cronbach’s alpha of at least 0,7) for the learning style under consideration. Table 43 shows the number of students per learning style.

Table 43 ATP – learning style – distribution of students

LS	active	reflective	sensing	intuitive	sequential	global	visual	verbal
N	52	25	65	36	18	38	109	12

LS= learning style; N= number of students

Table 44 provides an overview of the p-values of parametric and non-parametric statistics for the learning style as independent and usage variables and main usage factors as dependent variables.

Table 44 ATP – the impact of learning style on content use – p-values

	Act/Ref	*Sen/Int*	*Seq/Glo*	*Vis/Ver*
time on content module ATP	0,961	0,614	0,527	0,828
time on animation sequences ATP 1-4	0,650	0,774	0,630	0,473
control of ATP animation	0,454	0,993	0,736	0,269
use of single ATP animation sequences	0,244	0,870	0,888	0,993
use of audiovisual content collection	0,679	0,452	0,420	0,456
use of films and menu	0,378	0,904	0,958	0,026 (ver)
use of quiz and quiz videos	0,836	0,375	0,875	0,876
use of notes	0,267	0,349	0,371	0,801
use of guided tour	0,088 (act)	0,887	0,739	0,603
use of sitemap	0,330	0,395	0,725	0,162
use of back and one-page-up button	0,586	0,308	0,888	0,430
start of explorative tour (positive load on main usage factor)	0,466	0,066 (int)	0,483	0,781
start of sitemap (negative load on main usage factor)	0,466	0,066 (sens)	0,483	0,781
use of glossary and pre-defined links	0,974	0,496	0,155	0,755

p-values of ANOVA and U test for usage variables and main usage factors. The entries in parentheses show which learning style (e.g. active or reflective) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.2.1.4.1 Use of ATP content

No impact of the different learning styles on the use of the ATP content could be revealed.

3.2.1.4.2 Navigation and use of learning support features

Results of the U-test according to Mann and Whitney showed an influencing trend of the learning style act/ref on the use of the guided tour (p=0,088) with active learners using the guided tour more intensively.

The results are presented in further detail in table 45 as well as in figure 47.

Table 45 ATP – the impact of learning style act/ref on navigation

	active		reflective	
	N = 52		N = 25	
	M	SE	M	SE
use of guided tour	*0,212*	*0,177*	*-0,209*	*0,142*
start of guided tour	0,9	0,2	0,3	0,1
time on guided tour	80,8	26,3	45,3	29,3

Impact of learning style act/ref on navigation: factor values of main usage factor “use of guided tour” (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on this usage factor.

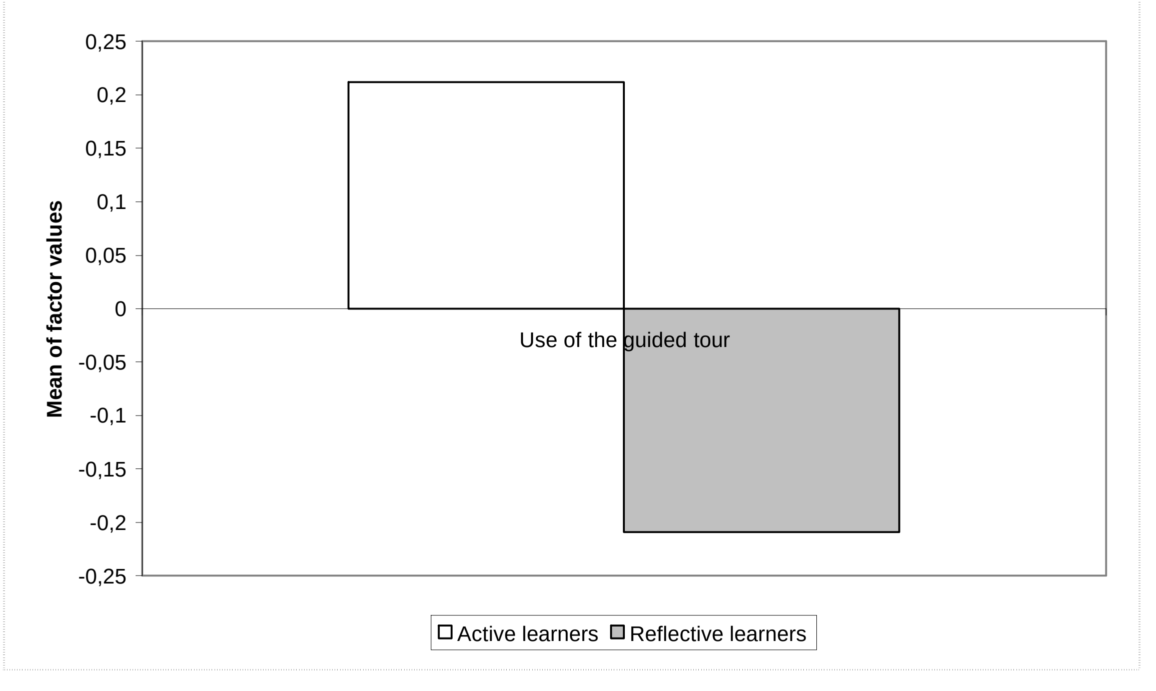

Figure 47 ATP – the impact of learning style act/ref on navigation: factor values of main usage factor “use of guided tour”.

Results of the U-test according to Mann and Whitney showed an influencing trend of the learning style sensing/intuitive to start the working session either with the explorative tour or a look on the sitemap (p=0,066). Intuitive learners tended to start with the explorative tour whereas sensing learners tended to start with the sitemap.
The results are presented in further detail in table 46 as well as in figure 48.

Table 46 ATP – the impact of learning style sen/int on navigation

	sensing		intuitive	
	N = 65		N = 36	
	M	SE	M	SE
start of explorative tour or sitemap	*-0,112*	*0,119*	*0,279*	*0,225*
start of explorative tour	0,5	0,1	0,7	0,2
start of sitemap (st)	0,9	0,1	0,6	0,1

Impact of learning style sen/int on navigation: factor values of main usage factor “start of explorative tour or sitemap” (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on this usage factor.

Figure 48 ATP – the impact of the learning style sen/int on navigation: factor values of main usage factor “start of explorative tour or sitemap”

Results of the U-test show a significant impact of the learning style vis/ver on the use of films and the menu (p=0,026) with verbalizers using these features more intensively.
The results are presented in further detail in table 47 as well as in figure 49.

Table 47 ATP – the impact of learning style vis/ver on navigation/content use

	visual N = 109		verbal N = 12	
	M	SE	M	SE
use of films and menu	*0,054*	*0,099*	*0,962*	*0,447*
time on cinema (all films)	15,0	6,0	76,6	35,9
clicks on menu	1,0	0,1	1,4	0,3

Impact of learning style vis/ver on content use and navigation: factor values of main usage factor “use of films and menu” (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on this usage factor.

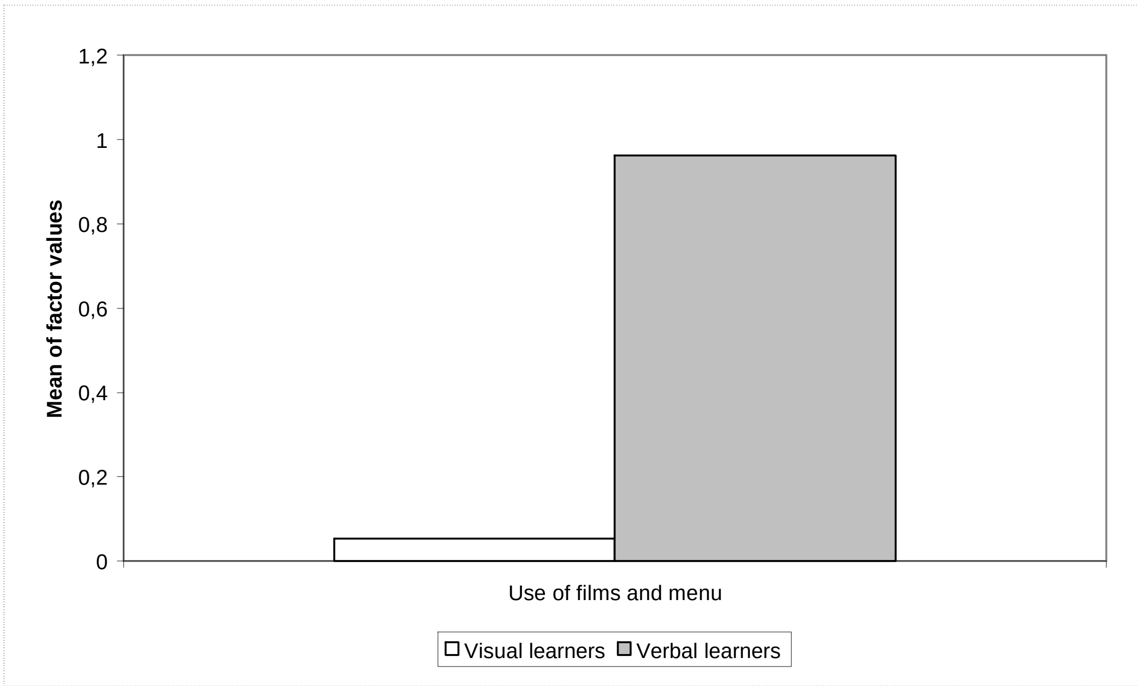

Figure 49 ATP – the impact of learning style vis/ver on content use and navigation: factor values of the respective main usage factor.

No impact of the learning style glob/ seq on navigation and the use of learning support features could be revealed.

3.2.2 Collaborative learning

In this chapter the results of students learning with the software in dyads are presented. The main usage factors resulting from the principle component analysis were further analyzed with respect to the impact of the animation design.

3.2.2.1 Main usage factors

11 main usage factors resulted from the principle component analysis. Table 48 shows the usage variables loading on the different main usage factors. As described above, some usage variables load negatively.

Table 48 ATP – collaborative learning – main usage factors & variables

main usage factor	*variables (load strength in parentheses)*
use of ATP content module	time on animation sequences ATP 1-4 (-0,86) time on content module ATP (-0,71)
use of single ATP animation sequences	time on sequence ATP 1 (0,76) time on sequence ATP 2 (0,86) time on sequence ATP 3 (0,90) time on sequence ATP 4 (0,76)
control of ATP animation	control of ATP animation (- 0,80)
use of audiovisual content collection	control of films and animations (0,85) time on 3D-lab (0,80)
use of films	time on cinema (0,85)
use of quiz and quiz videos	clicks on quiz videos (0,93) time on quiz videos (0,91) clicks on quiz (0,65)
use of notes and glossary	time on open notes (0,91) clicks on notes (0,88) clicks on glossary (0,61)
use of guided tour	time on guided tour (0,77) start of guided tour (0,74)
use of sitemap	time on sitemap (0,87)
start of sitemap and use of back and one-page-up button	clicks on back button (0,84) clicks on one page up button (0,51) start of sitemap (st) (0,69)
use of index and menu	clicks on index (0,76) clicks on menu (0,76)

Main usage factors and the usage variables loading on them ≥ 0,5 and ≤ -0,5.

The usage variables not loading on any main usage factor with at least ± 0,5 were “start of sitemap (tt)” (max. on “control of ATP animation” with 0,43), “start of explorative tour” (max. on “use of guided tour” with 0,43) and “clicks on link” (max. on “use of notes and glossary” with 0,48). In the group learning situation no usage variable was loading on two factors with at least 0,5.

Normal and skewed distribution of main usage factors

The resulting main usage factors served in the further analysis as dependent variables. Kolmogorov-Smirnov tests showed a normal distribution of the usage variable “time on content module ATP” and the main usage factors “use of single ATP animation sequences”, “start of sitemap and use of back and one-page-up button” and “use of index and menu”. These factors were calculated with respect to usage differences by means of ANOVAs. The usage variables “time on ATP animation sequences 1-4” and “control of ATP animation” as well as the other main usage factors showed a skewed distribution. Accordingly, usage differences were calculated with U tests.

3.2.2.2 Impact of animation design

The analysis of the impact of animation design was carried out with a total of 87 student groups. Table 49 shows the distribution of the groups to the different software versions.

Table 49 ATP – collaborative learning – distribution of students to the software variants

	software version			
	3D-dynamic	**2D-dynamic**	**with signals**	**without signals**
Number of groups	43	44	48	39

Table 50 provides an overview of the p-values of parametric and non-parametric statistics with the animation design serving as independent and the usage variables and main usage factors as dependent variables.

Table 50 ATP – collaborative learning – the impact of animation design on hypermedia use - p-values

	3D-dynamic/ 2D-dynamic	*with/without signals*
time on content module ATP	0,173	0,370
time on animation ATP 1-4	0,302	0,376
control of ATP animation	0,009 (3D-dynamic)	0,610
use of single ATP animation sequences	0,877	0,544
use of audiovisual content collection	0,622	0,138
use of films	0,690	0,871
use of quiz and quiz videos	0,120	0,562
use of notes and glossary	0,083 (2D-dynamic)	0,122
use of guided tour	0,653	0,053 (without)
use of sitemap	0,741	0,844
start of sitemap and use of back and one-page-up button	0,864	0,888
use of index and menu	0,717	0,721

p-values of ANOVA and U test for all usage variables and main usage factors. The entries in parentheses show which design feature (e.g. with or without signals) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.2.2.2.1 Use of ATP content

Results of the U-test according to Mann and Whitney showed a significant impact of the software version “3D/2D-dynamic animation design” on the active control of the ATP animation (p=0,009). Students working with the three-dimensional CD version used the interface to control the animation more often than the group using the two-dimensional version.

No impact of the presence/absence of signals on the use of the ATP content could be revealed.

The results are presented in further detail in table 51 as well as in figure 50.

Table 51 ATP – collaborative learning – the impact of 3D/2D dynamic animation design on content use

	3D-dynamic		**2D-dynamic**	
	N = 43		N = 44	
	M	SE	M	SE
control of ATP animation	2,3	0,8	0,8	0,3

Impact of a 3D/2D-dynamic design of the ATP animation on the control of the ATP content module: number of clicks.

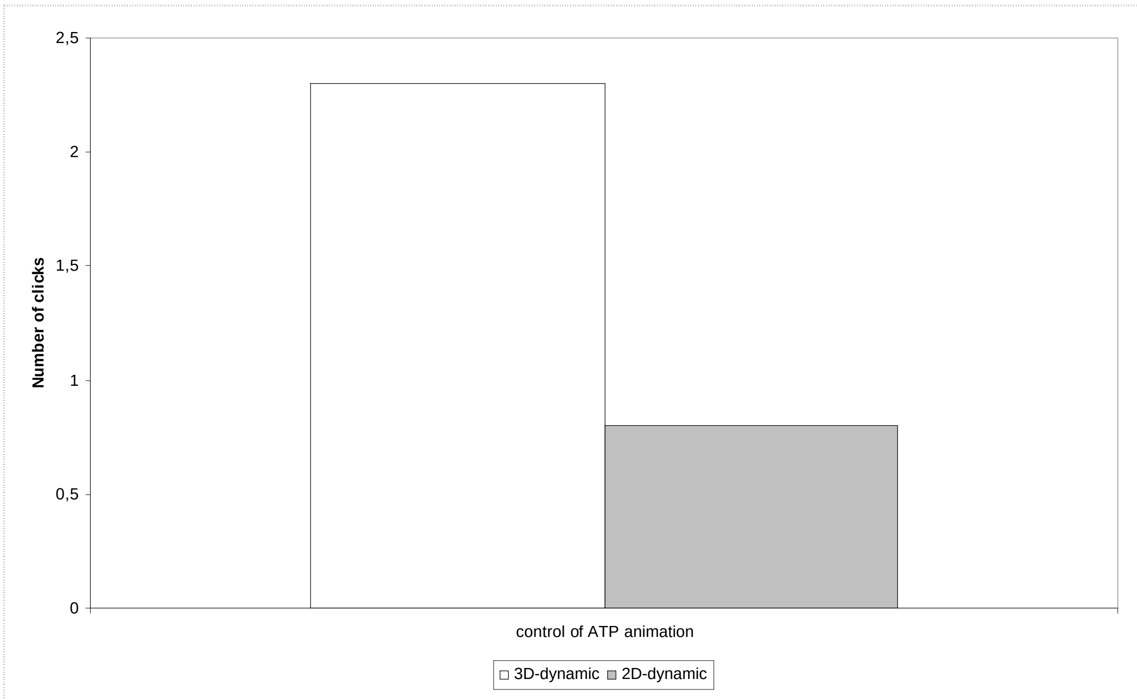

Figure 50 ATP – collaborative learning – the impact of 3D/2D dynamic animation design on the control of the ATP content module: number of clicks.

3.2.2.2.2 Navigation and use of learning support features

Results of the U-test according to Mann and Whitney indicate an influence of the software version "3D/2D-dynamic animation design" on the use of the notes and the glossary (p=0,083) and an almost significant influence of the software version "with/without signals" on the use of the guided tour (p=0,053). Students working with the 2D-version used notes and the glossary more intensively than the 3D-group. Students working with the animation version with no signals used the guided tour more intensively.

The results are presented in further detail in table 52 and 53 as well as in figure 51 and 52.

Table 52 ATP – collaborative learning – the impact of 3D/2D dynamic animation design on the use of learning support features

	3D-dynamic N = 43		2D-dynamic N = 44	
	M	SE	M	SE
use of notes and glossary	*-0,130*	*0,145*	*0,127*	*0,157*
clicks on notes	0,3	0,1	0,4	0,1
time on open notes	4,6	2,2	10,0	3,6
clicks on glossary	1,2	0,4	1,4	0,4

Impact of a 3D/2D-dynamic design of the ATP animation on the use of learning support features: factor values of main usage factor “use of notes and glossary” (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on this usage factor.

Figure 51 ATP – collaborative learning – the impact of 3D/2D dynamic animation design on the use of learning support features: factor values of main usage factor “use of notes and glossary”.

Table 53 ATP – collaborative learning – the impact of the presence/absence of signals on navigation

	with signals		**without signals**	
	N = 48		N = 39	
	M	SE	M	SE
use of guided tour	*-0,204*	*0,122*	*0,251*	*0,180*
start of guided tour	0,4	0,1	0,6	0,2
time on guided tour	22,4	11,6	40,1	17,3

Impact of the presence/absence of signals on navigation: factor values of main usage factor “use of guided tour” (*italics*); time (seconds) and number of clicks of the usage variables loading ≥ 0,5 and ≤ - 0,5 on this usage factor.

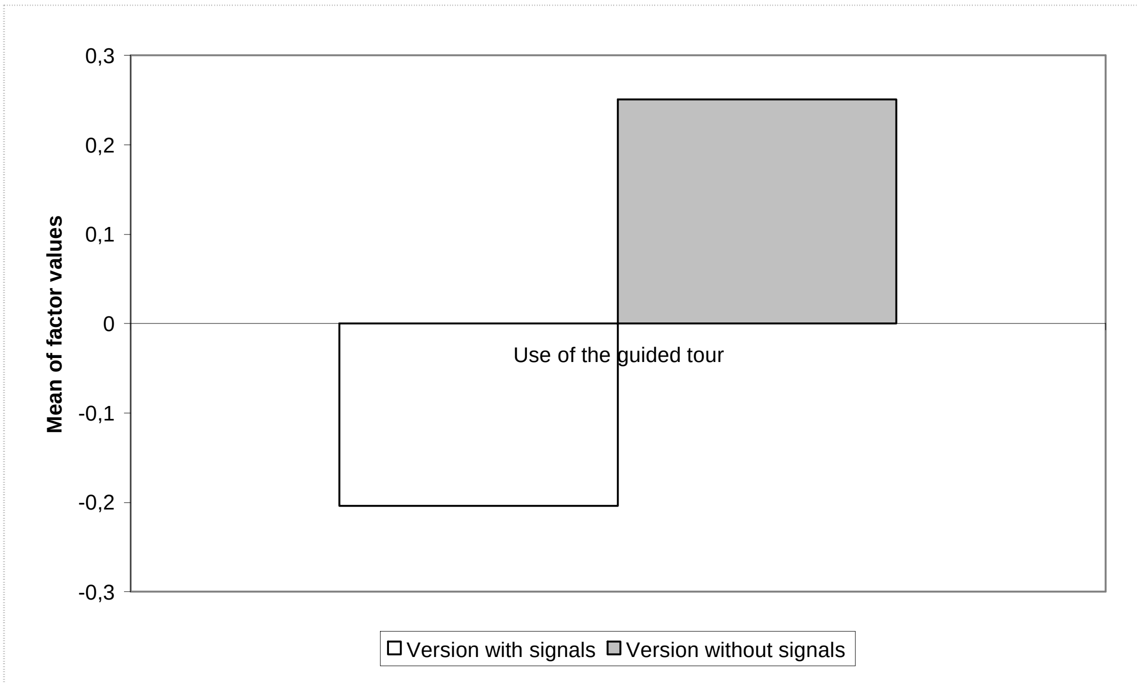

Figure 52 ATP – collaborative learning –the impact of the presence/absence of signals on navigation: factor values of main usage factor “use of guided tour”.

3.2.3 Summary of results – module “ATP synthase”

The results are summarized in two sections: one dealing with

- the impact of animation design; the other with
- the impact of learner characteristics on software use.

3.2.3.1 Impact of animation design

3.2.3.1.1 Individual learning

In the individual learning situation the results of parametric and non-parametric statistics revealed different impacts of the animation design on hypermedia use:

a) use of ATP content
   - a 3D-dynamic design led to a more intensive control activity when using the ATP animation
   - the animation including signals led to a longer usage time of the content module ATP; the version without signals supported a more intensive control activity when using the ATP animation

b) navigation and use of learning support features
   - a 3D-dynamic design led to a more intensive use of the glossary; a 2D-dynamic design to a more intensive use of the quiz, the quiz videos and the guided tour as well as to a more pronounced tendency to navigate with the back and one-page-up button.

The results are summarized in table 54.

Table 54 ATP – summary of results – individual learning – the impact of animation design on hypermedia use

	3D-dynamic/2D-dynamic animation design	*with/without signals*
time on content module ATP		with
control of ATP animation	3D-dynamic	without
use of quiz and quiz videos	2D-dynamic	
use of guided tour	2D-dynamic	
use of back and one-page-up button	2D-dynamic	
use of glossary and pre-defined links	3D-dynamic	

Module “ATP synthase” (individual use): dependent variables of hypermedia use that were influenced by the content design. The entries show which design feature (e.g. with or without signals) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.2.3.1.2 Collaborative learning

In the collaborative learning situation also the results of parametric and non-parametric statistics showed an impact of animation design on hypermedia use:

a) use of the ATP content
   - a 3D-dynamic design led to more intensive control activity when using the ATP animation

b) navigation and use of learning support features
   - a 2D-dynamic design of the ATP animation led to a more intensive use of the notes and the glossary
   - the animation without signals led to a more intensive use of the guided tour.

The results are summarized in table 55.

Table 55 ATP – summary of results – collaborative learning – the impact of animation design on hypermedia use

	3D-dynamic/ 2D-dynamic animation design	*with/without signals*
control of ATP animation	3D-dynamic	
use of notes and glossary	2D-dynamic	
use of guided tour		without

Module "ATP synthase" (collaborative use): dependent variables of hypermedia use that were influenced by the content design. The entries show which design feature (e.g. with or without signals) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

3.2.3.2 Impact of learner characteristics

In the individual learning situation the results of parametric and non-parametric statistics showed different impacts of prior domain knowledge, spatial ability and learning style on hypermedia use:

a) use of the ATP content
   - low prior domain knowledge led to a longer use of the content module ATP on the whole as well as of the single ATP animation sequences
   - low spatial ability led to a longer use of the single ATP animation sequences

b) navigation and use of learning support features / content collection
   - low prior domain knowledge led to a more intensive use of notes, high prior domain knowledge to a more intensive use of the film collection and the main menu
   - low spatial ability led to a more pronounced tendency to start with the explorative tour, high spatial ability to start with the sitemap
   - the active learning style led to a more intensive use of the guided tour
   - the intuitive learning style led to a more pronounced tendency to start with the explorative tour, the sensing learning style to start with the sitemap
   - the verbal learning style led to a more intensive use of the film collection and the main menu.

The results are summarized in table 56 and 57.

Table 56 ATP – summary of results – the impact of prior knowledge / spatial ability on hypermedia use

	Prior domain knowledge	*Spatial ability*
time on content module ATP	low	
time on animation ATP 1-4	low	
use of single ATP animation sequences	low	low
use of films and menu	high	
use of notes	low	
start of explorative tour		low
start of sitemap		high

Module “ATP synthase” (individual use): dependent variables of hypermedia use that were influenced by learner characteristics. The entries show if low or high prior domain knowledge / spatial ability led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

Table 57 ATP – summary of results – the impact of learning style on hypermedia use

	Act/Ref	*Sen/Int*	*Seq/Glo*	*Vis/Ver*
use of films and menu				verbalizer
use of guided tour	active			
start of explorative tour		intuitive		
start of sitemap		sensing		

Module “ATP synthase” (individual use): dependent variables of hypermedia use that were influenced by learner characteristics. The entries show which learning style (e.g. active or reflective) led to a more intensive use (longer time or higher number of clicks) of the respective dependent variable.

4 Discussion

In engineering as well as in the natural sciences visualizations, computer animations and 3D-models are frequently used (e.g. Lu et al. 2007; O'Day 2006; Lowe 2001; see also introduction chapter). Special 3D-features, animations or additional visualizations such as close-up-views for example are integrated with the intention to enhance motivation and/or to clarify complex spatial structures. As the development of sophisticated software of this type is work intensive and costly (e.g. Chittaro & Ranon 2007; see also introduction chapter), the investigation of the interplay between design features, learner characteristics and software use is called for. This is what the present study intends to shed light on. As outlined in the earlier chapters, in the present study the students were instructed to explore a complex hypermedia environment to learn about different aspects of cell biology. Results of logfile tracking indeed show various impacts of content design as well as learner characteristics on hypermedia use. These results shall be discussed in the following.

After a brief discussion of the methods used (section 4.1), section 4.2 interprets the results regarding the influence of 3D-models, close-up-views and 3D/2D-static picture design on hypermedia use. Here specifically the work with the module variants on structure and function of the plant and animal cell are analyzed. The results are discussed for individual and collaborative learning (dyads).

Section 4.3 discusses the results on the impact of animation design such as 3D- vs. 2D-design or the presence vs. absence of signals on hypermedia use. Here specifically the work with the software variants of the module on the structure and function of the ATP synthase is looked at. In line with section 4.2, the results are presented for individual and collaborative learning (dyads).

The influence of learner characteristics was analyzed for students learning individually only. Research results gained by comparing individual and collaborative learning showed that the usage behaviour of individual subjects can rarely be generalized to teamwork (Rebetez et al. 2006; Schnotz et al. 1999) as social interaction and collaborative load interfere with cognitive processes of the individual learners (Dillenbourg 2006). Moreover, the impact of learner characteristics was not investigated for each software version separately but generally for all versions. This is due to the multitude of investigated variables and the unequal distribution regarding the usage of various dependent variables: the usage patterns found would have required a very high number of analyses and due to resource restrictions it was decided in the first step to focus on the impact of the learner characteristics more generally. As the participants were randomly assigned to work with the different software versions, a general analysis of main effects seemed acceptable. The discussion of the results is also presented in section 4.2 and 4.3.

4.1 Discussion of methods

In the study presented a variety of impact factors on the use of hypermedia have been investigated. The results provide new insights regarding the role of content design as well as individual differences on learning with hypermedia environments. The different analyses reveal that these independent variables exhibit a strong impact on the use of content as well as on navigation and the use of learning support tools. As with every scientific work the methodology chosen for this study has certain advantages, but also disadvantages which will be discussed in the following paragraphs.

<u>Realistic learning scenarios: internal and external validity</u>

Research of recent years very often has focused on investigations in restrictive settings leading to very specific and often contradicting results. These studies exhibit great internal validity, but little scope for the generalization of results (see also Ludwigs 2006). Against this background the research presented here aimed to take forward a broad insight into the learning processes of students using complex hypermedia environments. The realistic learning scenario of a classroom situation was chosen to improve external validity and thereby allows for a generalization of results. Naturally, the author acknowledges that at the expense of internal validity such a field study exhibits more confounding factors than a study that is carried out in a media lab.

<u>Time span of learning sessions</u>

When creating a more realistic learning scenario one question to address is the time that should be given to the learners to solve a task. Time varies widely between the broad range of studies that have been carried out in the field. In the restrictive settings of the studies of Mayer and his colleagues on the CTML-model, learning processes often were limited to 180 seconds. This is contrasted by studies of de Westelinck et al. (2005) designing larger learning modules to be processed by the students and allowing for longer learning sessions (see also Tabbers et al. 2004, de Jong & van der Hulst 2002). The contrasting approaches seem to suggest that the optimal study time for a certain task is yet to get established, therefore in the meantime more attention should be paid to monitoring the study time as a co-variable. Due to practical deliberations, in the present dissertation the time to work with the software was restricted to 20 minutes per session. As the students had to deal with a complex hypermedia environment this can still be considered a short amount of time. However, the students seemed to familiarize themselves with the software quickly, therefore the 20 minute working session seemed to be a sufficient amount of time to support a realistic learning scenario. Moreover, the time span chosen seemed well adapted to the rhythm of German school lessons of 45 minutes each.

Offline and online media

The study was carried out with a software on cell biology, i.e. an offline medium. It is postulated however that the specific investigation could have been performed online also leading to comparable results as the time of the working sessions was limited and the hypermedia environment offers a lot of content to explore. Against the background that in general online users are more or less anonymous and it is difficult to track, let alone validate user data provided via internet, the use of the software seemed the more appropriate approach to investigate the relationship between software design and learners' needs under more controlled conditions. However, the transfer of results from offline to online results seems feasible, for offline media can easily be transformed for online use anyway. Moreover, often online and offline media are developed in parallel, as actually was the case with the used product also. Accordingly, the results retrieved by testing the offline learning environment seem fit to be used for the development of online content modules of databases.

Data analysis – log file tracking and principle component analysis

As mentioned in the introduction, one major advantage of log file recording is the fact that the method can be, in contrast to e.g. verbal protocol analyses, integrated in the learning environment as a seamless part, not exhibiting the risk of interfering with the learning process (de Jong & van der Hulst 2002; Winne et al. 1994). It is therefore considered a non-intrusive method to capture a participant's navigation performance, paths and use of various media (Liu & Kešelj 2007; Lawless et al. 2002, Barab et al. 1996) thereby to get an insight into the individual's learning process.
Chen et al. (1995) claim that the different techniques of logfile tracking are still limited in two ways. First, some of the analysis processes are primarily manual and very time-consuming: even the sophisticated techniques proposed by Winne et al. (1994) require heavy manual conceptualization and could be considered very subjective. Second, logfiles present statistically aggregated data such as total time spent or number of nodes visited at a descriptive level only. Some authors therefore argue that it remains difficult to draw conclusions from observations by means of logfiles to underlying learning processes (Unz

2000). However, as physical manipulations require prior cognitive processes supporting the operations they can help to identify the cognitive knowledge aquisition processes of the learner (Goodyear et al. 1991). Furthermore, the study of navigation through log files enables the examination of complex learning variables such as problem solving, metacognitive strategies and planning (Lawless & Brown 1997).

Overall, log file tracking is considered an important method to predict different search and learning strategies when using hypermedia learning environments (Gerjets & Scheiter 2003). Recording study actions in different learning environments enables the researcher to relate the strategies used to the user's learner characteristics, such as spatial ability, prior knowledge or learning style. On the other hand logfiles can also be correlated with differing design features of the hypermedia content and environment. This in turn enables the impact of the design on the use of hypermedia to be revealed thereby helping designers in a second step to adapt the software in the most profitable way for the users.

Since log files can contain enormous amounts of data, methods for data reduction with a minimum loss of information are needed (Richter et al. 2003). For this purpose in this dissertation a principal component analysis was applied to get a reduced number of main usage factors from a bigger variety of usage variables. Factorial analysis or principle component analysis (PCA) routinely applied in science (e.g. Nagabhushan et al. 2006; Kumar et al. 2004; Wu et al. 2003) apparently has been rarely used in context of logfile analyses (e.g Juvina & Herder 2005; Herder & van Dijk 2004). This was somehow surprising as it seems to be a promising method for meaningful data reduction. The present study therefore supports a further development and establishment of PCA as a promising method in the research field of learning with new media enabling insights in complex usage processes including the impact of a variety of variables.

4.2 Module “plant and animal cell”

As outlined in detail in the methods chapter, in the first part of the software working session the students had to focus on the CD module “plant and animal cell” and here especially on the structure and function of certain cell organelles (cytoskeleton). The task required information search as well as working on the content module of the plant and animal cell. In this context the Quicktime Virtual Realities, animated flights, close-up-views and 3D-pictures that were integrated in the most sophisticated software variant were considered to

a) fulfill a motivational purpose and to increase the involvement of the students;
b) clarify complex spatial structures;
c) support the understanding of the cell’s structure-function-dependencies.

Accordingly, in the following their impact on software use and the learning process of students will be discussed. Moreover, for the individual learning situation the influence of the learner characteristics prior domain knowledge, spatial ability and learning style will be interpreted.

4.2.1 Impact of 3D-models, close-up-views and 3D/2D-static picture design

In this section specifically the impact of content design, i.e. the presence/absence of 3D-models and close-up-views as well as a 3D/2D-static picture design on the software use and learning process of students learning either individually or in dyads will be discussed.

4.2.1.1 Individual learning

In the individual learning situation the results of parametric and non-parametric statistics revealed different impacts of the content design variants on hypermedia use:

a) the presence/absence of 3D-models and of close-up-views had an impact on content use and navigation;

b) a 3D/2D-design of a static picture showed no impact on the hypermedia use at all;

c) decreasing visual details of the content presentation led to an increasing use of certain learning support features.

In case of the 3D-models and close-up-views the study results supported the first hypothesis raised in the introduction chapter. In case of the 3D/2D-design of a static picture the hypothesis was falsified:

If students use a complex hypermedia environment, the content design variants
presence/absence of 3D-models,
presence/absence of close-up-views,
and 3D/2D-design of a static picture
will each have a significant impact on the use of the content as well as on navigation and the use of learning support tools (e.g. a glossary)!

In the following paragraphs the impacts of content design on hypermedia use are discussed in further detail.

<u>Impact of 3D-models on the use of the cell content and learning outcome</u>

Obviously, 3D-models offer many potential benefits as they allow a more realistic and detailed presentation of topics; complex structures can be viewed from different angles and moreover, spatial relationships between structures be simulated (e.g. Brenton et al. 2007; Chittaro & Ranon 2007; John 2007). However, empirical research on the educational value of these models is scarce altogether, and the research results to date have indicated no advantages, but sometimes even detrimental learning outcome to result from usage of a 3D-presentation format (e.g. Keller et al. 2004; Byrne 1996).

The findings of this study comparing CD versions with or without 3D-models showed that students spent significantly more time with the content module “plant and animal cell” when 3D-models were present. This suggests that the integration of additional audiovisual material may have seemed useful to focus the attention of students on central aspects of the to-be-learned content for a longer time. However, a more detailed analysis revealed that the integration of 3D-models did not influence the usage time of the part of the content module with central task relevance, i.e. the cross section of an animal and plant cell with explanations about the cell’s organelles. Apparently the 3D-models did not increase nor decrease motivation to spend time on the cross section. Moreover, in the present study 3D-models did not generally lead to an improvement of the learning success, i.e. no general impact of 3D-models on the understanding of spatial structures or structure-function-dependencies could be detected. The analysis of the knowledge test post sofware use showed that 3D-models were beneficial for users with high spatial ability only (Huk 2006). This result supports the ability-as-enhancer hypothesis proposed by Mayer (2001) which suggests that mainly high spatial ability learners profit from complex 3D-models in hypermedia environments. High spatial ability learners can devote more cognitive resources to build referential connections between visual and verbal representations of complex audiovisual material than low spatial ability learners. Findings of Levinson et al. (2007) support this further.

Impact of close-up-views on the use of the cell content and learning outcome

The cognitive theory of multimedia learning (CTML; Mayer 2001) and the integrated model of text and picture comprehension (ITPC; Schnotz 2005) take into account the fact that descriptive and depictive presentations within hypermedia environments are assumed to be processed in two different chanels. The two models differ in their interpretation of the role played by higher level cognitive processes in mental model construction but make similar predictions regarding a number of design principles for instructional multimedia material (e.g. modality principle, contiguity principle). ITPC further suggests the structure-mapping principle that predicts that pictures enhance comprehension only if the learning content is visualized in a task-appropriate way as the form of visualization affects the structure of the mental model (Schnotz 2005). According to this structure-mapping principle the two strategies that were used in the present study to present pictorial material, i.e. variants with and without close-up-views, were expected to be differently effective. The log file analysis however revealed that close-up-views did not entice the users to lay a stronger focus on the cell content module: when close-up-views were absent, students actually spent more time on the content module and clicked more frequently on technical terms marked in the cross section. As outlined earlier, the screen featuring the cell’s cross section provides the task relevant information on the structure and function of different cell organelles in an auditive way. Thus, it is likely that students using the less sophisticated software version may have had more capacities left to concentrate on the narration whereas learners using the version with close-up-views had to process the picture as well as the narration and therefore may have had less capacities left for auditive information processing. Apparently, the close-up-views represented additional extraneous cognitive load that hindered learning of the auditorily presented material and the logfile analyses showed that students did not try to compensate this additional load by intensifying their use of the content module.

The ITPC model predicts that if a picture is added to a text and if the same amount of mental effort is invested in learning, verbal information becomes less important (Schnotz 2005). The analysis of the knowledge tests post software use indeed revealed a better auditory recall of students using the hypermedia version without close-up-views (Huk & Steinke 2007). Brünken et al. (2005) detected a beneficial effect of visual linkages (connecting lines) as inter-representational hyperlinks in multimedia learning material also. The results of the present study indeed indicate that this visualization technique seems more appropriate for the non-hierarchical structure presentation in which pieces of information are not related in a simple cause and effect chain, but rather inter-connected in a multi-dimensional way. In natural sciences this is a common phenomenon and hypermedia learning environments may be well suited to support explorative learning.

Moreover, the analysis of the knowledge transfer tests post software use revealed that only students with high spatial ability benefited from the variant without close-up-views (Huk & Steinke 2007). Students with low spatial ability could not profit from the reduced visualization variant with visual linkages (connecting lines) only. These results are again in line with the ability-as-enhancer hypothesis of Mayer and Sims (1994). An alternative explanation for impact differences may be associated with students misjudging the complexity of the to-be-learned material. Low spatial ability students in particular seem to be prone to this effect: in measurements of perceived cognitive load they stated that the variant with visual linkages only possessed a clear structure and was easy to comprehend. In the knowledge transfer test however, their performance was comparatively low. The impact of individual differences on the beneficial effect of design features was also shown in the investigation of Brünken et al. (2005) in which inter-representational hyperlinks were only effective for learners with higher expertise.

Impact of the 3D/2D-design of a static picture on hypermedia use

With the data analyzed no impact of the static picture design, be it in a three- or two-dimensional way, on the use of the hypermedia learning environment could be detected. It can be assumed however, that the amount of additional information inherent in the 3D-presentation of a static picture is less than that of additional 3D-models with their dynamic and interactive character. The results suggest that a 3D/2D-static design variation does not necessarily lead to a change of cognitive load which in turn may result in differing usage patterns of the hypermedia environment. However, previous studies demonstrated that a high degree of realism in pictures may be less effective for learning than a simpler picture design provided that the latter includes the essential conceptual information (e.g. Tversky et al. 2002; Dwyer 1978). Against this background the further enhancement of naturalistic elements or in contrary further simplifications in the illustration of a cell may lead to usage differences. Further investigations are necessary to shed light on this question.

Impact of content design on navigation and the use of learning support features

The results of the present study show that the content design exhibits an impact on the navigation behaviour also. Users seem to be influenced by the content design parameters in different ways. The pattern emerging when analyzing the content use of both modules actually was the following: when 3D-models were present or close-up-views were absent (visual linkages, i.e. connecting-lines only) the students used the sitemap more intensively. On the other hand, when 3D-models were absent or close-up-views were present students showed a more intensive use of the guided tour. The presence of 3D-models or less sophisticated visual linkages seem to stimulate a more global information processing behaviour by means of using the sitemap. On the other hand the presence of close-up-views seem to lead to a more sequential usage pattern by means of using the guided tour.

Moreover, an impact of content design on the use of learning support features, i.e. the use of quiz and quiz videos could be observed: the gradual decrease of audiovisual elements was linked to an increase in the use of these features. The descriptive data reveal especially an increase in the use of quiz videos. The latter feature as well as the models the students may have used to get a better idea of the spatial structure of the cell.

The results suggest that effects caused by certain content design parameters on cognitive processing may lead to a change in the knowledge acquisition behaviour also. This interpretation is supported by previous analyses of Steinke et al. (2003c) which showed that a three dimensional design of an animation led to a significant increase in the use of the glossary. The influence of the software design on the use of knowledge acquisition tools such as the glossary was also shown in other investigations (see Winter et al. 2003; Stiller & Mate 2003).

4.2.1.2 Collaborative learning

In the collaborative learning situation the results of parametric and non-parametric statistics showed different impacts of the investigated content design variants on hypermedia use:

a) the presence/absence of 3D-models had an impact on content use and navigation;

b) the presence/absence of close-up-views had an impact on navigation and the use of learning support tools;

c) a 3D/2D-design of a static picture had an impact on the use of the respective content.

A comparison of the impact of software design on individual and collaborative use shows that the second hypothesis holds true for close-up-views and the 3D/2D-static picture design:

If students learn in small groups (dyads) while using a complex hypermedia environment the impact of the design of audiovisual content on the software use will be different to the impact on students learning solitarily!

In the case of the 3D-models the second hypothesis was falsified as the impact on students working individually and in groups was the same.

As stated above, for individual as well as group learning situations 3D-models exhibited a stable impact to the same effect: the presence of these models led to a significant more intensive use of the cell content and the sitemap, their absence to a more intensive use of the guided tour. Even if additional collaborative load is to be assumed for the students learning in dyads the impact of such complex features as 3D-models seems to be stable (see Dillenbourg 2006). As mentioned above, on the other hand changes of usage behaviour could be observed when investigating the impact of close-up-views as well as static picture design. To this end navigation behaviour and usage of the content mainly changed when students were working in groups. Such changes might be due to social interaction or collaborative load (see Dillenbourg 2006). When comparing the impact of the 3D/2D-static picture design differences between individual and collaborative learning could be observed: while there were no usage differences of the content when students were working individually, in the group learning situation the dyads using the version with a 3D-representation of the cell’s cross section spent significantly less time with the content. Possible explanations may be seen in

a) the 3D-version to mainly support dyads to extract the relevant information from the illustration in a fast and efficient manner;

b) the 2D-version to motivate only dyads to work with the content for a longer time.

Comparing individual and collaborative learning as regards the time spent on the cross section supports the first explanation: students working in groups spend over 100 seconds less on the 3D-version. The higher cognitive load of the 3D-picture seems therefore to be compensated by the collaborative learning process (see also Dillenbourg 2006).

4.2.2 Impact of learner characteristics

The results of parametric and non-parametric statistics showed differences in the impact of the investigated learner characteristics (see also methods chapter) on hypermedia use:

a) prior domain knowledge and spatial ability had an impact on all levels of hypermedia use;

b) the four learning style (LS) dimensions had different impacts:

    a. LS active/reflective and LS sensing/intuitive had an impact on navigation and the use of learning support tools;

    b. LS visual/verbal exhibited an impact on navigation;

    c. LS sequential/global showed no influence on hypermedia use at all.

Therefore the third hypothesis raised in the introduction holds true only for prior domain knowledge and spatial ability:

If students use a complex hypermedia environment the learner characteristics prior domain knowledge, spatial ability and learning style will each have an impact on the use of the content as well as on navigation and the use of learning support tools!

In case of the learning style the third hypothesis was falsified. None of the learning style dimensions showed an impact on the use of the content. Moreover the learning style dimension “global/sequential” showed no influence on hypermedia use at all.

In the following paragraphs the impact of the investigated learner characteristics on hypermedia use are discussed in further detail.

4.2.2.1 Impact of prior domain knowledge and spatial ability

<u>Impact of prior domain knowledge on the use of the cell content</u>

Learning is considered to be an active process whereby students acquaint themselves with new information, building on knowledge that they already possess (e.g. Kalyuga et al. 2003; Mayer 2001). As there is a lot of evidence that users’ prior domain knowledge has a significant impact on learning with hypermedia (e.g. van Oostendorp & Juvina 2007; Dillon & Jobst 2005), many previous studies addressed the impact of prior domain knowledge on the learning process and performance (Kalyuga 2005; Müller-Kalthoff & Möller 2005; Möller & Müller-Kalthoff 2000; MacGregor 1999; Lawless & Kulikowich 1998).

In line with the findings of studies conducted earlier, the results of the present study reveal that users with low prior domain knowledge spent more time on the content. A likely interpretation can be seen in the fact that the low prior knowledge group may need more time to understand the content and therefore spends more time with the modules that are of crucial importance to solve the tasks at hand. This interpretation is supported by results of Huk et al. (2005) which show that learners with high prior knowledge show a significantly more positive attitude towards complex hypermedia software at the same time experiencing less cognitive load than users with low prior knowledge. It seems therefore likely that in the learning situation of the present study the low prior knowledge group devoted more time to the cell content to overcome a stronger cognitive load. Previous multimedia research also shows that for high prior knowledge learners it seems much easier to generate mental images as they read or listen to narration, i.e. this learner group easily copes with verbal and visual representations in the short-term memory at the same time (Mayer 1997).

Impact of prior domain knowledge on navigation and the use of learning support tools

In the study presented learners with low and high prior knowledge showed different information search behaviour. Students with low prior domain knowledge more often tended to work their way from the start screen using either the site map or the explorative tour. The descriptive data revealed that this usage behaviour more often was accompanied by the use of the back button. A surprising finding of this study was that they did not more often start with the guided tour, a feature that is considered to be especially helpful for students with low prior knowledge. Previous studies (Möller et al. 2000; Mc Donald & Stevenson 1999; Shapiro 1999) showed that hierarchical or concept maps can support the learning process of low prior knowledge learners. Other authors (e.g. Hofman & van Oostendorp 1999) found the contrary: concept maps can even hinder mental model construction of learners with low prior knowledge. The results indicate that is seems necessary to provide users of complex hypermedia environments with different possibilities of navigational help. At the same time especially learners with low prior knowledge seem to need further help as the frequent use of the back button may indicate a considerable uncertainty of this user group as regards what to do next or how to navigate. Against this background the plea that navigation and guidance design should be carefully adapted to the learner's prior knowledge as postulated by different authors (e.g. de Jong 2005) is strongly supported. Moreover, the integration of additional learner support tools should prove especially useful for learners with low prior knowledge (see also Ludwigs 2006).

Different studies have already identified characteristic navigation profiles of certain user types (see e.g. Lawless et al. 2002; MacGregor 1999; Lawless & Kulikowich 1998): the feature explorer is described by Lawless and Kulikowich (1998) as a type of user attracted by special features of the learning environment. MacGregor (1999) identifies in one of three navigation profiles the "video viewer", who spends a high amount of the time viewing videos and in this preference for audiovisual material shows similarity to the feature explorer. According to Lawless the feature explorer has a low level of domain knowledge whereas the video viewer is described by MacGregor to have some prior knowledge. Both authors point out that cognitive characteristics of the users, such as the level of prior domain knowledge, do exhibit an influence on their navigational behaviour – findings which are also supported by the present study.

Impact of spatial ability on hypermedia use

In the section on the impact of content design it was already discussed that multimedia features had a different impact on students with high and low spatial ability. Results of the logfile analysis of all software variants showed moreover general differences in the use of the hypermedia system between learners with different spatial ability: users possessing high spatial ability were clicking significantly more often on the technical terms presented on the graphical display of the cell's cross section. They also used navigational help such as pre-structured links and learning support tools as the notepad more frequently. On the other hand, users with low spatial ability spent significantly more time on additional films and 3D-models in the audiovisual content collection of the hypermedia environment. An additional assessment of students' attitude towards the two software variants differing by the presence/absence of 3D-models (Huk et al. 2003d) showed that students with high spatial ability had a more positive attitude when using the version including 3D-models whereas students with low spatial ability preferred the graphically less sophisticated version. Knowledge tests post software use moreover showed that the learning performance increased with increasing spatial ability of the participants. These findings can be interpreted in two ways:

- audiovisual features better support students with high visual spatial ability to use the content and hypermedia environment. They have more cognitive resources left to concentrate on the relevant content and to use navigation and learning support features, e.g. the notepad to sustain their knowledge acquisition process.
- students with low visual spatial ability seem to have more difficulties in the cognitive processing of audiovisual content and are therefore more likely to get distracted rather than sustained in their knowledge acquisition process. This interpretation of cognitive overload or distraction of the low spatial ability group is supported by the assessment of the students’ attitude vis-a-vis the software.

Further support is provided by the ability-as-enhancer hypothesis (see also introduction chapter 1.2.1.2): the high spatial ability students’ deeper involvement in the learning process may lead to a better learning outcome of this user group.

Recent research has shown that spatial ability has an impact on the comprehension of 3D-computer visualizations (Keehner et al. 2004). Investigations focussing on the modality effect (Moreno and Mayer 1999) and the temporal contiguity effect (Mayer, 2001; Mayer and Sims 1994) also observed that sophisticated graphical instructional design features seem more beneficial for students with high spatial ability than for students with low spatial ability.

As mentioned earlier in other studies learners have been clustered into user groups identified as “video viewers” or as “feature explorers” with a high percentage of users with low prior knowledge. Such groups might also include a greater share of people with low visual spatial ability. Andris (1996) also investigated the correlation of modality preferences and navigation. He found that visually dominant students spent less total time in a geology lab simulation than their visually less apt counterparts. This was interpreted as the visually dominant students having more capacity for the assimilation of audiovisual information.

The spatial ability of users exhibited not only an impact on the content use but also on navigation and the use of learning support tools. Users with high spatial ability used pre-defined links more often. Calcaterra et al. (2005) found that students with a high ability to orient themselves within the software showed more dynamic browsing patterns documented e.g. by a higher number of mouse movements, by jumps in the virtual reality section as well as by more changes of perspective and frequency of zooming. One may interpret these findings assuming that the students tried to get a more detailed picture from various perspectives which may also be the case in the present study. Results of the latter proved the high spatial ability learners to show a more intensive use of e.g. the notepad feature: apparently, this user group had more cognitive resources left to get more detailed information as well as to better structure this knowledge by writing it down. Personal differences regarding the taking of notes were also found in the study of Efaw & Bailey (2004) though the focus of that study laid on the impact of learning styles.

4.2.2.2 Impact of learning style (LS)

When investigating the impact of individual differences cognitive and learning style represents a major research topic (e.g. Graff 2006; Karns 2006; Dillon & Jobst 2005, Morrison et al. 2003; Ford & Chen 2000; Paolucci 1998) and impacts of different cognitive/learning styles on navigation behaviour have frequently been reported. In this section the influence of the four different learning style dimensions measured with Felder’s Index of Learning Styles on the use of the tested hypermedia environment are discussed in greater detail.

<u>Impact of LS “active / reflective” on navigation and the use of learning support tools</u>

The learning style dimension “active/reflective” showed a considerable impact on navigation and the use of learning support tools. Reflective learners showed a more intensive use of the sitemap, started more frequently with the explorative tour and used the glossary more often. For active learners it could be observed that they started more often with the guided tours and more intensively used the quiz and quiz videos.

The active/reflective learning style dimension according to Felder shows similarities with the learning style dimension impulsivity/reflectivity measured with Kagan’s instrument which is closely associated with field-dependence/ field-independence (see Felder & Spurlin 2005; Felder & Brent 2005; Cassidy 2004). Hereby reflective learners are reported as more field-independent and impulsive (active) learners as more field-dependent. The results of the present study also indicate with respect to different navigation preferences that active learners are more similar to field-dependent users. On the other hand however reflective learners show similarities with field-dependent as well as field-independent learners.

Chen and Macredie (2004) present a learning model with field-independent learners more likely to use serialistic patterns and field-dependent learners using more global/wholistic patterns of information processing when navigating through hypermedia systems (see also the introduction chapter, p14, figure 3). Their study suggests that overview diagrams and hierarchical maps should assist field-dependent learners. Ford & Chen (2000) also found that field-dependent learners seem to make greater use of the map. The results of the present study suggest that reflective learners seem to adopt such a wholistic strategy by using the map more intensively than active learners.

Chen and Macredie (2004) also claim that field-dependent individuals prefer suggested paths to flexible paths whereas it is the other way round with field-independent learners. Nevertheless, in the present study it is the user group of the active learners – as is true for the field-dependent learners – who more often tend to use guided paths for knowledge acquisition.

Another observation with respect to navigation and the use of learning support tools was that reflective learners started more often with the explorative tour and used the glossary more often than active learners. The influence of learner characteristics on the use of learning support tools has also been identified previously by different authors (e.g. Bartholomé et al. 2006, Andris 1996). Andris investigated the relationship of students' field dependence/ independence and navigation. He found that the field independent students spent more time with the glossary. The results of the present study suggest that apart from their wholistic approach reflective learners also seem to adopt preferences of field-independent learners by exploring the hypermedia environment freely and using the glossary for knowledge acquisition. Another usage difference found was that active learners were using the quiz and quiz videos more intensively. According to Liu & Reed (1994) such a usage pattern would be similar to that of field-dependent users. Results of their study revealed that field-dependent users more frequently selected video media and multiple choice when using a hypermedia system.

Impact of LS "sensing / intuitive" on navigation and the use of learning support tools

The learning style dimension "sensing/intuitive" showed an impact on navigation. Intuitive learners started more often with the explorative tour and used the back button more often. Felder and colleages (Felder & Spurlin 2005; Felder & Brent 2005) describe intuitive learners to prefer discovering possibilities whereas sensing learners tend to like learning facts. This might provide the explanation for the more explorative approach of intuitive learners accompanied by a frequent use of the back button as a method to avoid rapid disorientation. In the intuition-analysis dimension described in Allinson and Hayes (1996, see also Cassidy 2004; Felder & Spurlin 2005; Felder & Brent 2005) intuitive learners are further described to adopt a global perspective. As in the case of field-dependent learners this might have resulted in a more frequent use of the sitemap which couldn't be observed in the log file analysis.

With respect to the use of learning support tools results show that intuitive learners drew on the quiz and quiz videos more intensively than their sensing counterparts. Carver et al. (1999) report that students classified as intuitive with Felder’s inventory are particularly attracted by the possibility to view the lesson’s objectives when learning with a hypermedia course. This might be true for the intuitive students of the present study also. As intuitors like to rapidly explore the main ideas and relationships of the to-be-learned content using the quiz seems to present a good method to find out more about the main concepts and goals of the hypermedia environment.

In line with literature (e.g. Chen & Macredie 2004) this study’s results for the sensing/intuitive learning style dimension support the necessity to adapt navigation and learning support tools to individual differences as certain features seem to attract user groups with certain learner characteristics. However, whether different knowledge acquisition processes lead to differences in the learning outcome still has to be investigated. Alty et al. (2006) showed in their study that intuitive users performed significantly better when learning statistics with multimedia presentations than their sensing counterparts. As the mode of presentation had no influence on the performance of the students, their explanation for this result was that the more theoretical nature of the material might have favoured the intuitive students. Felder et al. (2002) also found that intuitors often outperformed sensors in engineering courses and explained the differences by the fact that traditional courses often emphasize the theoretical over the practical. This might also be taken into account for the content design of hypermedia environments for different user groups. Alty et al. (2006) furthermore postulated that a practical task or also the use of video material (which had not been used in their study) might increasingly favour sensing students. However, in their study the students had not had the possibility to interact with the multimedia material. Therefore the role of interactivity for the learning process of users with different learning styles remains an open question.

Impact of LS “global / sequential” on hypermedia use

No impact of the learning style dimension “global/sequential” on the hypermedia use could be revealed. According to Felders’ index of learning styles sequential learners tend to gain understanding in linear steps, while global learners tend to learn in large jumps and try to grasp the big picture of the to-be-learned content. Because of the similarities with wholists and serialists and here with field-dependent/-independent learners (see also Dünser & Jirasco 2005; Felder & Spurlin 2005; Felder & Brent 2005; Cassidy 2004; Chen & Macredie 2004) it was expected to find similar usage patterns. Such differences could not be found. One reason might be that in comparison to the sample size for the analysis of the other learning styles, the group of individuals showing at least a moderate tendency to the global or sequential learning style was relatively small. Accordingly, it might be necessary to investigate a larger number of students with the Felder instrument to find usage differences between sequential and global learners.

Impact of LS "visual / verbal" on hypermedia use

The visual-verbal axis shows the most unequal distribution of the learners to the different preferences with a very high number of students rating themselves to be visual learners and very few students the opposite. Alty et al. (2006) also report such an unequal distribution in their study and claim that Felder's test tends to always indicate a predominance of visual learners and results therefore need to be considered with the necessary caution.

In the present study differences in the use of the audiovisual content could not be found. However, the learning style dimension "visual/verbal" showed an impact on navigation with visual learners showing a preference to start with the sitemap and also using the back button more often. According to Felders' index of learning styles visual learners remember best what they see, e.g. diagrams, flow charts or time lines whereas verbal learners get more out of written and spoken explanations. As the graphical design of the sitemap is similar to that of a diagram this navigation tool might better fit to the preferences of visual learners.

4.3 Module “ATP synthase”

As outlined earlier multimedia and hypermedia learning environments these days increasingly integrate dynamic visualizations, i.e. 3D-models, animations etc. (e.g. Brenton et al. 2007; Despotakis et al. 2007; Ferens et al. 2007; Bodemer et al. 2005; Lowe 2004). However, currently intuition and artistic judgement appear to be the dominant guiding forces for their design as relatively little evidence from empirical research exists regarding what features of an instructional animation may potentially benefit learners and how learners deal with these materials when they encounter them (Ploetzner & Lowe, 2004). To enhance the knowledge in this field in the present study the software usage patterns when working with different animation designs, specifically, the presence of 3D/2D animations and the presence/absence of signals was investigated. Moreover the impact of certain learner characteristics, i.e. prior domain knowledge, spatial ability and learning style, was assessed for the individual learning situation. The analysis of logfiles suggests that the different design features as well as individual differences exibit on different levels impacts on software use. The results will be discussed in the following sections of this chapter.

4.3.1 Impact of animation design

In this section specifically the impact of animation design, i.e. a 3D/2D-animation design and the presence/absence of signals on the software use and learning process of students learning either individually or in dyads will be discussed.

4.3.1.1 Individual learning

In the individual learning situation the results of parametric and non-parametric statistics showed different impacts of the animation design variants on hypermedia use:

a) the 3D/2D-animation design had an impact on all levels of hypermedia use;

b) the presence/absence of signals had an impact on the content use only.

Therefore the first hypothesis raised in the introduction held true for the impact of the 3D/2D-design of the animation only:

If students use a complex hypermedia environment the
3D/2D-design of an animation,
and presence/absence of signals in an animation
will each have a significant impact on the use of the content as well as on navigation and the use of learning support tools (e.g. a glossary)!

In the following paragraphs the impact of animation design on hypermedia use is discussed in further detail.

<u>Impact of animation design on content use and learning outcome</u>

Empirical studies focusing on the impact of 3D-visualizations in learning environments are scarce and inconsistent (see e.g. Keller et al. 2004). While some authors assume that viewing dynamic 3D-animations improves mental model construction (Wu & Shah 2004; Hays 1996) other studies highlight the danger of a cognitive overloading of the working memory, especially in learners with low spatial ability (Huk 2006; Mayer & Sims 1994).

Various studies investigate the impact of signals in animations. Some of these studies demonstrate a positive effect of signals on the learning outcome whereas others come to the conclusion that signalling does not necessarily improve learning (an overview is provided in de Koning et al. in press).

In the present study the animation design exhibited an impact on the content use of the hypermedia environment. A presence of signals had the effect that students spent significantly more time with the ATP content module. On the other hand, students using the version with the 3D or the non-signalled version were significantly more active in controlling (stopping /

restarting) the animation explaining the ATP synthase.The literature suggests that interactive user control can counteract the cognitively demanding aspects of animations, i.e. their “fleeting nature” (Tversky et al. 2002): the possibility of the users to adjust the speed of the animation to the individual needs by pause and rewind features might therefore lead to a deeper processing of the to-be-learned content. To this end Burke et al. (1998) reported that students provided with learner control/navigational aids showed greater use of animations. However, the analysis of knowledge acquisition tests does not support the assumption of deeper processing by more control activities. In fact, learners’ understanding was better fostered by the 2D-version and remembering was better when the signalled version was used. That means that students’ learning seemed to be better supported by spending more time with the content than by rising their control activities. It seems that more control couldn’t facilitate the understanding of the more demanding 3D- or non-signalled versions of the animation. Interestingly, in more restricted experimental settings the impact of 3D/2D-animation design seemed prone to change: when showing the animation to students by LCD projector the 3D-version fostered understanding better than the 2D-version (Huk et al. in press). Against this background better learning with the 2D-version might be explained by students using other features of the hypermedia environment (see following paragraph) to improve their performance.

Other results of Huk et al. (in press) and Steinke et al. (2003c) on perceived cognitive load and attitude reveal that students liked the 3D-animation variants better than the 2D-format: students working with the hypermedia version that contained the three-dimensional animation stated significantly more often that they wanted to see such features integrated in instructional material. It is possible that the presentation of a well-designed three-dimensional animation increases students’ motivation to deal with the material. The more positive attitude towards the 3D-version did not lead to a longer use of the ATP content module, but it seemed to enhance students’ engagement regarding the learning task, i.e. it led to an increased control of the ATP animation. However, this did not include a better learning outcome of the 3D-group, at least not in the short run. More investigations regarding the linkage between attitude, software use and learning outcome are needed.

Impact of animation design on navigation and the use of learning support features

Apart from the use of the content the animation design has additional implications for the use of the hypermedia learning environment. In line with a previous analysis of Steinke et al. (2005) it was expected that a three-dimensional graphical design would lead to an increase in the use of learning support tools such as the glossary and notes. This expectation is based on neuropsychological research which provides evidence that a positive mood can systematically affect cognitive processing and hence improves creative problem solving (e.g. Ashby et al, 2002). The results of the log file analysis revealed indeed a trend in the 3D-group to a more intensive use of the glossary and the pre-defined links. On the other hand a 2D-design led to a significant more intensive use of the quiz, quiz videos and other navigation features such as the guided tour and the back- and one page up-buttons.

In line with a study of Steinke et al. (2005) the presence/absence of signals showed no impact on navigation and the use of learning support tools. However, literature suggests that a visualization of difficult terms may increase the use of learning support tools such as a glossary or the use of notepads to support the process of learning. In practice, such an increase could not be found and this suggests that the integration of signals might be effective enough to stimulate a more intensive work on the content and to grasp the important information without looking for further details by using external tools such as the glossary. This interpretation is supported by the longer use of the content module ATP as well as the better learning outcome with respect to remembering when students were using the signalled version.

The pronounced difference in impact between the 3D/2D-animation and the version with/without signals respectively on navigation and the use of learning support tools indicates that content design properties can have quite different impacts on the processing strategies of the learners. The presence of visual cues seems to directly stimulate a more intensive use and cognitive processing of the content. The 3D/2D-presentation format seems to indirectely have a stronger stimulating influence leading to different processing strategies with respect to the use of learning support tools and information search strategies. The influence of the software design on the use of knowledge support tools, such as the glossary was also shown by other investigations (Winter et al. 2003; Stiller and Mate 2003). Especially as regards expensive 3D-presentation formats it is therefore necessary to adjust them effectively to the features of the surrounding hypermedia learning environment.

4.3.1.2 Collaborative learning

In the collaborative learning situation the results of parametric and non-parametric statistics showed an impact of animation design on different levels of hypermedia use, i.e. the use of the content as well as navigation and the use of learning support features:

a) the 3D/2D-animation design had an impact on the use of the content and learning support tools;

b) the presence/absence of signals had an impact on navigation only.

A comparison of the software design impact on individual and collaborative use shows that the second hypothesis holds true for both animation design parameters:

If students learn in small groups (dyads) while using a complex hypermedia environment the impact of the design of audiovisual content on the software use will be different to the impact on students learning solitarily!

Research results gained by comparing individual and collaborative learning show that the usage behaviour of individual subjects can rarely be generalized to teamwork (Rebetez et al. 2006; Schnotz et al. 1999) as social interaction and collaborative load interfere with cognitive processes of the individual learners (Dillenbourg 2006). A comparison of the log files in this study revealed that the impact of content design on dyads and individuals differs in dependence to the software design parameter.

One persistent impact could be shown for the 3D/2D-dynamic design: in both settings, i.e. students learning individually as well as in dyads, students were more active controlling the animation when they were offered the 3D-variant. Even if collaborative load is to be assumed for the students learning in dyads to some extend the impact of complex 3D-features seems to be stable. This was also found in the study’s first part looking at 3D-models of the cell.

With respect to the use of learning support tools an interesting change occurred with the 2D-group using the glossary and the notepad more intensively whereas the opposite could be observed with individual learners, i.e. the 3D-group was using the glossary more intensively. Other usage differences between individual and collaborative learning occurred with respect to the presence/absence of signals: the impact on the content use disappeared when students were learning in groups. Moreover students using the version without signals used the guided tour more intensively than the group using the version with signals. Such usage differences might be due to social interaction and collaborative load effects when users learn in groups (see also Dillenbourg 2006).

4.3.2 Impact of learner characteristics

In the individual learning situation the results of parametric and non-parametric statistics showed different impacts of the learner characteristics on hypermedia use:

a) prior domain knowledge had an impact on all levels of hypermedia use;

b) spatial ability had an impact on content use and navigation;

c) the four learning style (LS) dimensions exhibited different impacts:

   a. LS active/reflective and LS sensing/intuitive showed an impact on navigation;

   b. LS visual/verbal had an impact on content use and navigation;

   c. LS sequential/global showed no influence on hypermedia use at all.

Therefore the third hypothesis raised in the introduction holds true for the learner characteristic prior domain knowledge only:

If students use a complex hypermedia environment the learner characteristics prior domain knowledge, spatial ability and learning style will each have an impact on the use of the content as well as on navigation and the use of learning support tools!

In case of spatial ability and the learning style the third hypothesis was falsified. None of the learning style dimensions showed an impact on the use of learning support tools and only the “visual/verbal” learning style showed an impact on content use. In line with the analysis of the module “cell” the learning style dimension “global/sequential” showed no influence on hypermedia use at all.

In the following paragraphs the impacts of the investigated learner characteristics on hypermedia use are discussed in further detail.

4.3.2.1 Impact of prior domain knowledge and spatial ability

Impact of prior domain knowledge on hypermedia use

In line with earlier findings, the results of the software usage analysis of students tackling the task on the structure and function of the ATP synthase revealed again that users with low prior domain knowledge spent more time with the content. A likely explanation can be seen in the fact that the low prior knowledge group may need more time to understand the content and therefore spends more time with the screens that are of crucial importance to solve the tasks at hand. This interpretation is supported by results of Huk et al. (2005) which show that learners with high prior knowledge show a significantly more positive attitude towards the software at the same time experiencing less cognitive load than users with low prior knowledge. It seems therefore likely that the latter spend more time with the animation to overcome a stronger cognitive load. Previous multimedia research also shows that for learners with high prior knowledge it seems much easier to generate mental images as they read or listen to narration, i.e. this learner group easily copes with verbal and visual representations in the short-term memory at the same time (Mayer 1997).

Additional usage differences with respect to the use of learning support tools could be observed. Users with low prior knowledge used the notepad more intensively. On the other hand, the high prior knowledge group was using additonal films more intensively. This supports the claim of Kalyuga (2005) that depending on their level of prior domain knowledge users need different features to support meaningful knowledge construction. The availability of different navigation and learning aids may therefore facilitate the comprehension of the to-be-learned content for users with different levels of prior knowledge. In the present study an intense use of the notepad by low prior knowledge learners could be observed. This indicates that such an additional learning support tool is especially appreciated by this learner group. Apparently, written reflection seems to be a valuable help in hypermedia learning. This is supported by literature also, Ludwigs (2006) e.g. showed that such a learning support improved understanding of examinees and proved especially helpful for students with low prior knowledge.

The intense use of the ATP content might to a certain extent compensate for lower prior knowledge. By investigating the effect of a 3D/2D-design of an animation on users with different levels of prior knowledge in a restricted setting (animation only shown by LCD projector) Huk et al. (2005; 2003b) found that the 2D-presentation enhanced the test performance of users with high prior knowledge. When the animation was embedded in the hypermedia learning environment the learning outcome showed a comparable pattern but with less pronounced differences. This indicates that the possibility to construct knowlege in the hypermedia environment helps low prior knowledge learners to improve their knowledge acquisition.

Impact of spatial ability on hypermedia use

Apart from prior domain knowledge, spatial ability is considered to be of central importance for navigation and multimedia learning (e.g. Keller et al. 2006; Wu & Shah 2004; Keehner et al. 2004). When tackling the task on the ATP synthase users with low spatial ability spent significantly more time on the single audiovisual sequences of the ATP module. Longer usage of the audiovisual material could also be observed in the first working session on the cell. As outlined already, one possible explanation might be that people with high spatial ability grasped the content of the three dimensional presentations faster and used them therefore more efficiently. In line with Dias and Sousa (1997) who stress that the handling of different tasks within multimedia software represents a high cognitive challenge to the users, it is possible to postulate that students with low spatial ability suffer from cognitive overload and therefore have to invest more time to understand the content of the complex visualizations. Previous assessments of students' attitude towards two software variants differing by the presence/absence of 3D-models (Huk et al. 2003d) support this assumption: the study showed that students with high spatial ability had a more positive attitude towards the software version including complex 3D-features whereas students with low spatial ability preferred a simplified 2D-version.

With respect to navigation there was a difference in the usage process with a trend to a more frequent start of the explorative tour by users with low spatial ability. On the other hand, users with high spatial ability preferred to start with the sitemap. The sitemap seems not to be preferred by the users with low spatial ability although it can be assumed that this user group needs more orientation support. Different authors (e.g. Hays 1996) demand a further clarification of the needs of low spatial ability learners. Such deliberations seem especially important for complex hypermedia environments as free exploration in such surroundings may generate a heavy cognitive load (e.g. Gerjets & Scheiter 2003; Paas 2003).

4.3.2.2 Impact of learning style

When investigating the impact of individual differences, cognitive and learning style represents a major research topic (e.g. Graff 2006; Karns 2006; Dillon & Jobst 2005;

Morrison et al. 2003; Ford & Chen 2000; Paolucci 1998). In this chapter the impact of the four different learning style dimensions measured with Felder's Index of Learning Styles on the use of the tested hypermedia environment are discussed in detail.

Impact of LS "active / reflective" on navigation

The learning style dimension "active/reflective" showed an impact on navigation. Specifically, it could be observed that active learners used the guided tours more intensively. This is in line with the interpretation of results of the first working session on the structure and function of the cell: with respect to different navigation preferences active learners show more similarities to field-dependent than to field-independent users. Chen and Macredie (2004) claim that field-dependent individuals preferred suggested paths to flexible ones.

Impact of LS "sensing / intuitive" on navigation

The learning style dimension "sensing/intuitive" showed an impact on navigation. In line with the observation of the first learning session on the cell intuitive learners started more often with the explorative tour. Felder and colleagues (Felder & Spurlin 2005; Felder & Brent 2005) describe intuitive learners to prefer discovering possibilities whereas sensing learners tend to like learning facts. This might provide an explanation for the more explorative approach of intuitive learners. In the intuition-analysis dimension described in Allinson and Hayes (1996, see also Cassidy 2004; Felder & Spurlin 2005; Felder & Brent 2005) intuitive learners are further described to adopt a global perspective. As in the case of field-dependent learners this was assumed to result in a more frequent use of the sitemap; the log file analysis however did not sustain this assumption.

Impact of LS "global / sequential" on hypermedia use

No impact of the learning style dimension "global/sequential" on the hypermedia use could be revealed. According to Felders' index of learning styles sequential learners tend to gain understanding in linear steps, while global learners tend to learn in large jumps and try to grasp the big picture of the to-be-learned content. Because of the similarities with wholists and serialists and hereby with field-dependent/-independent learners (see also Dünser & Jirasco 2005; Felder & Spurlin 2005; Felder & Brent 2005; Cassidy 2004; Chen & Macredie 2004) it was expected to find similar usage patterns. This however was not the case and may be linked to the – compared to the sample size available for the analysis of the other learning styles - relatively small number of students who showed at least a moderate tendency towards the global or sequential learning style. Therefore, to find usage differences between sequential and global learners it might be necessary to analyze a larger number of students with the Felder instrument.

Impact of LS “visual / verbal” on hypermedia use

The visual-verbal axis shows the most unequal distribution of the learners to the different preferences with a very high number of students rating themselves to be visual learners and very few students the opposite. Alty et al. (2006) also report an unequal distribution in their study and claim that the Felder’s test tends to always indicate a predominance of visual learners and results need to be considered with the necessary caution.

However, certain learner types seem to prefer certain usage strategies when learning with hypermedia environments. In the present study verbal learners showed a more intensive use of films and the menu. According to Felders’ index of learning styles visual learners remember best what they see, e.g. pictures, films and demonstrations whereas verbal learners get more out of written and spoken explanations. As in the case of students with low spatial ability (for details see respective section) verbal learners might suffer from cognitive overload when watching audiovisual content.

5 Conclusions and outlook

This dissertation is an attempt to inform the debate that is already taking place on learning with hypermedia. Educational software increasingly finds its way into classroom learning. The multi- and hypermedia environments offered distinguish themselves by the integration of increasingly sophisticated design features which in turn impact among others on production time and costs. The question arises whether the currently available software products seem well adapted to users' needs ensuring effectiveness and efficiency of learning. While developing educational software the goal is to optimally support the process of learning and maximize the learning outcome. This is to be achieved by the proper design of the whole system as well as that of the content within the system. Furthermore, individual learner characteristics, e.g. prior domain knowledge, spatial ability and learning style, are to be taken into account as the latter play an important determining role regarding the way to learn with hypermedia systems.

A key question research is to address in this context concerns the way learner characteristics and content design properties are linked to navigation processes and knowledge acquisition strategies. A review of literature reveals that most studies conducted so far analyze the effects of single variables. Investigations on the learning process when using complex hypermedia environments and moreover the factors impacting on the software use are scarce still. Accordingly, there is a demand for further analyses aiming to shed light on the complex interplay of the different relevant parameters such as content design and learner characteristics. Moreover, ideally these studies are to draw on non-intrusive data sources such as log-files or observational data (see e.g. Bartholomé et al. 2006; Gerjets & Hesse 2004).

The presented doctoral thesis aims to bridge this gap: set in a realistic classroom scenario, the study captures a comprehensive image of the learning process with a complex learner-controlled hypermedia environment. The influence of content design is investigated by working with four software variants differing in their design. Moreover, the impact of individual learner characteristics on the learning process is assessed. Offering fresh insights into learning with hypermedia and extending the relevant theoretical framework in this field the study's findings contribute to the design of learning software that is well adapted to users' needs.

Specifically, three hypotheses focussing on the impact of content design and learner characteristics on the users' knowledge acquisition process were investigated; results reveal a complex picture:

The first hypothesis of this dissertation claims that the content design will have a far reaching impact on the use of the hypermedia environment:

If students use a complex hypermedia environment, each of the following content design features such as

- *presence/absence of 3D-models,*
- *presence/absence of close-up-views,*
- *3D/2D-design of a static picture,*
- *3D/2D-design of an animation,*
- *and presence/absence of signals in an animation*

will have a significant impact on the use of the content as well as on navigation and the use of learning support tools (e.g. a glossary)!

The hypothesis was falsified for the 3D/2D-design of a static picture and the presence/absence of signals in animations but held true for the other content design parameters. This suggests that

- not only the design of the whole hypermedia system but also that of single information nodes within such hypermedia systems indeed exhibit an impact on navigation and the use of learning support tools; this means that the content design exhibits a far reaching impact on the learners' processing strategies and use of the whole hypermedia environment;
- certain content design features such as complex 3D-visualizations impose a stronger impact than static pictorial or written elements;
- elements such as signals seem to have a more direct impact on cognitive processing whereas 3D-animations and the like seem to stimulate – together with additional features of hypermedia - the knowledge acquisition process more indirectely.

The second hypothesis claims that the impact of content design will be different for students working individually or in groups:

If students learn in small groups (dyads) while using a complex hypermedia environment the impact of the design of audiovisual content on the software use will be different to the impact on students learning solitarily!

The hypothesis was falsified for the presence/absence of 3D-models but held true for the other content design parameters. This suggests that

- results from individual learning cannot easily be transferred to collaborative learning as social processes interfere with the impact of content design;
- some content design features such as 3D-models seem to have a strong impact on hypermedia use – strong enough to be stable even if students work in small groups.

The third hypothesis focusses on learner characteristics and claims that individual differences will have a far reaching impact on hypermedia use:

If students use a complex hypermedia environment, the learner characteristics prior domain knowledge, spatial ability and learning style will each have an impact on the use of the content as well as on navigation and the use of learning support tools!

The hypothesis was falsified for learning style but held true for prior domain knowledge and spatial ability. A closer look at the results (see respective sections) suggests that of the investigated learner characteristics

- prior domain knowledge has on all levels a strong impact on hypermedia use;
- spatial ability shows a strong interaction with complex 3D-visualizations;
- learning style mainly has an impact on navigation and the use of learning support tools and much less impact on the content use than prior domain knowledge and spatial ability.

Moreover the impact of learner characteristics showed changes from the first to the second learning session. Reasons for that might be found in an increase in experience dealing with the hypermedia environment or the different tasks of the consecutive learning sessions. The latter interpretation is backed by a multitude of studies postulating that apart from learner characteristics the type of task plays a major role for learning with hypermedia (e.g. Chen & Paul 2003; Unz 2000; Calvi 1997; Chen & Rada 1996; Dee-Lucas & Larkin 1995). However, some features such as longer content use of learners with low prior domain knowledge or low impact of learning style on content use remained stable over the two learning sessions.

To describe complex usage processes of hypermedia environments in light of the cognitive load theory (CLT) Gerjets and Hesse (2004) propose a model with a focus on learner activities in hypermedia learning environments (see figure 1 of the introduction chapter). In this model it is proposed that learners' activities should be analyzed in terms of goals and strategies, assuming that processing strategies mainly depend on prior knowledge and expertise. Moreover, the processing strategies are influenced by learners' conceptions including a broad variety of beliefs, attitudes or study preferences. Recent studies (Opfermann 2008) have shown such an impact of attitudes and epistemological beliefs on hypermedia learning. In the model of Gerjets and Hesse (2004) the learning environment is described to have an impact on the processing strategies via the configuration of learner goals and thereby to have a moderating role between instructional design, cognitive load and learning outcome.

The results of this dissertation confirm the moderating role of the learning environment and learner characteristics on learner activities as proposed by Gerjets and Hesse (2004). Moreover the findings indicate possible extensions of the model:

- the content design of the hypermedia learning environment has a far reaching impact on the learners' activities and processing strategies without necessarily configuring the learner goals;
- the impact of the learning environment on learners varies depending on the learning situation, i.e. individual or collaborative learning, for collaboration load is interacting with the cognitive load imposed on the learners by the software design;
- besides prior knowledge other learner characteristics such as spatial ability and learning styles have an impact on the learners' activities and processing strategies – especially learning styles seem to have a strong impact on navigation behaviour.

Figure 53 shows the extended CLT model from Gerjets and Hesse (2004; adapted by Opfermann 2008) with the proposed extensions.

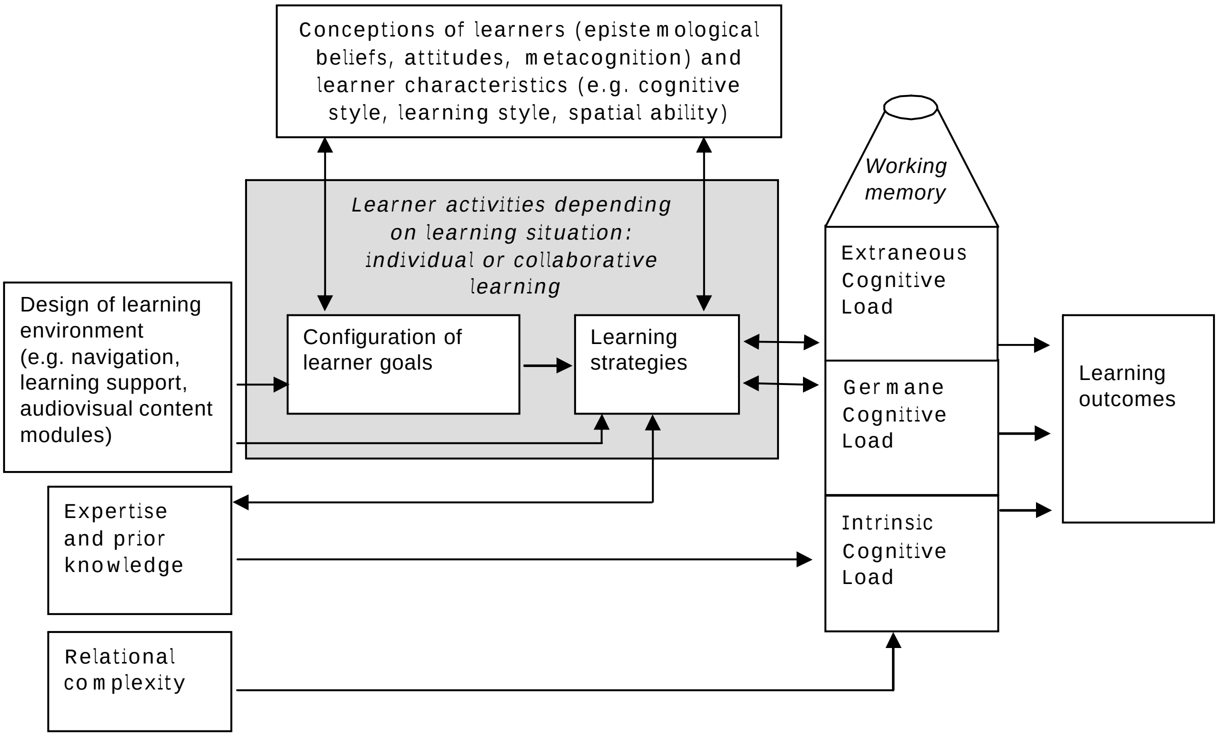

Figure 53 Learner activities, cognitive load, and learning outcomes (figure adapted from Gerjets & Hesse 2004 and Opfermann 2008)

Much remains to be learned regarding the way different learners perceive hypermedia systems with different design properties. It remains an open question whether a variation of the instructional design with the same content presented may lead to different usability and learning outcomes. To develop effective multimedia material for education it is necessary to understand the underlying learning processes when using the material. The educational approach depends among others on goals, target groups, content and learner characteristics.

More investigations are necessary to illuminate the complex interplay of content and hypermedia design, learner characteristics and other major impact factors such as the task type (see Gerjets & Hesse 2004). This includes more investigations on the far reaching impact of the design of audiovisual content on hypermedia usage patterns: not only the use of the content itself but also navigation and the use of other features, e.g. learning help tools, are influenced by varying multimedia content design. Alessi and Trollip (2001) postulate that educators should use a variety of multimedia materials and approaches to provide flexible learning environments that meet the needs of the greatest number of their learners. This is supported by a study of Huk et al. (in press) in which a change in learning outcome could be shown in a comparison of learning results achieved with viewing an animation a) solitarily and b) embedded within a complex hypermedia environment. Multimedia principles as stated by Mayer and other authors (e.g. Mayer 2005) can therefore not easily be applied to the use of multimedia in hypermedia environments (see also Opfermann et al. 2006).

However, professional e-learning software normally is available in one version only, namely the version the producers consider to be the best. Presently intuition and artistic judgement still seem to be guiding forces when designing animations (Lowe 2001). Against this background empirical investigations can create an important data basis for the future design of hypermedia learning environments which may in the best possible way take the users' needs into account and maximize the learning outcome. The study's results strongly support the claim of Alessi and Trollip (2001) showing that learners – due to differences in individual characteristics- approach work with a learning software in very different ways as they are to a varying extent stimulated by certain design features. Thereby the findings strongly build the case for a software to offer multiple design features for content presentation, navigation and learning support so that as many learners as possible could be as best as possible supported while learning with hypermedia and that learning success could be optimized.

Many authors (e.g. Chiu 2004) suggest using web usage mining techniques to support the development of hypermedia features. The latter would allow to dynamically adapt structure and content to fit users' browsing needs and assist user navigation based on past navigation history.

Furthermore, building on the CRIMP project's existing database and the dissertation presented more analyses should be undertaken with respect to learning style and collaborative work. To improve the generalizability of research results further it may moreover be beneficial to consider variations in the learning scenarios as well as to carry out experiments in other cultural contexts. A first step was undertaken with the piloting of the English version of the CD ROM with bilingual classes.

Improving the knowledge basis in this field will definitely help teachers, lecturers and software designers to choose the right instructional material for their students and/or to design multi- and hypermedia material themselves. The dissertation presented supports this process by offering some important insights in the complex processes taking place when learning with hypermedia environments.

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7 Annexes

As outlined in the methods chapter, the study was conducted in Germany, so naturally the German language versions of the instruments were used. To inform non-German speaking readers however in the following the English language versions are presented.

7.1 Instruction and declaration of consent

As outlined in the methods chapter, a standardized introduction including the following declaration of consent was read to the students and they were asked to sign it.

Information about objectives and general conditions of this investigation

With your participation in the study you have the opportunity to directly influence the future use of computer-aided learning programmes in undergraduate eduction.

It is the objective of this investigation to gain knowledge about learning processes taking place when working with multimedia applications. The central question to answer is the following: How useful is the application of learning software in educational settings?

The test will take place in 2 consecutive sessions. In the first session, with the aid of questionnaires we would like to assess your ability for spatial imagination, your learning style and your knowledge in cell biology (this is the subject of the CD-Rom). In the second session we want you to work with the software in order to document the utilisation of the programme and of course to assess the learning success.

Your taking part in this investigation is voluntary. If you do not want to take part, this has no negative consequences for you whatsoever. You will only give away the chance of taking an active part in the further development of learning software.

All data will be handled and processed anonymously. Your personal data cannot be traced back to you. Against this background the learning success of participants will not be shared with third parties (e.g. teachers!) nor will it be possible to provide individual feedback. Nevertheless, if you wish, we will inform you about the overall results of our investigation.

Declaration of consent:

I have read and understood the statements made above.
I am taking part in this study voluntarily.

date signature

7.2 Pre-test questionnaires

The pre-test questionnaires included tests on prior domain knowledge, spatial ability and learning style.

7.2.1 Questionnaire on prior knowledge of cell biology

*Please give a **short** answer using the empty boxes provided. In the multiple choice part you will be presented four alternatives. Only **one** of them is correct. Please tick off the correct answer.*

Please do not guess when answering!

---

1. Please describe the structure of the endoplasmatic reticulum (ER)!

2. Please describe the function of the endoplasmatic reticulum (ER)!

3. Please describe in a short answer the function of the golgi apparatus!

4. Please explain in a short answer the function of a proton gradient!

5. Name the organelle in which cell respiration takes place!

6. Which of the following statements describes the organelle for cell respiration best?

- it contains the enzyme complex for oxidative phosphorylation
- it contains the enzyme complex for oxidative hydrolysis
- it contains the enzyme complex for photo-phosphorylation
- it contains the enzyme complex for photosynthesis
- I don't know

7. Please describe the differences between plant and animal cells!

animal cell	plant cell

8. Which elements belong to the cytoskeleton?

- ER = endoplasmatic reticulum
- actin fibres
- dictyosom
- vacuoles
- I don't know

9. Which is the main function of ATP ?

- the storage of adenosine
- the storage of phosphate
- the storage of energy
- the formation of an electrochemical gradient
- I don't know

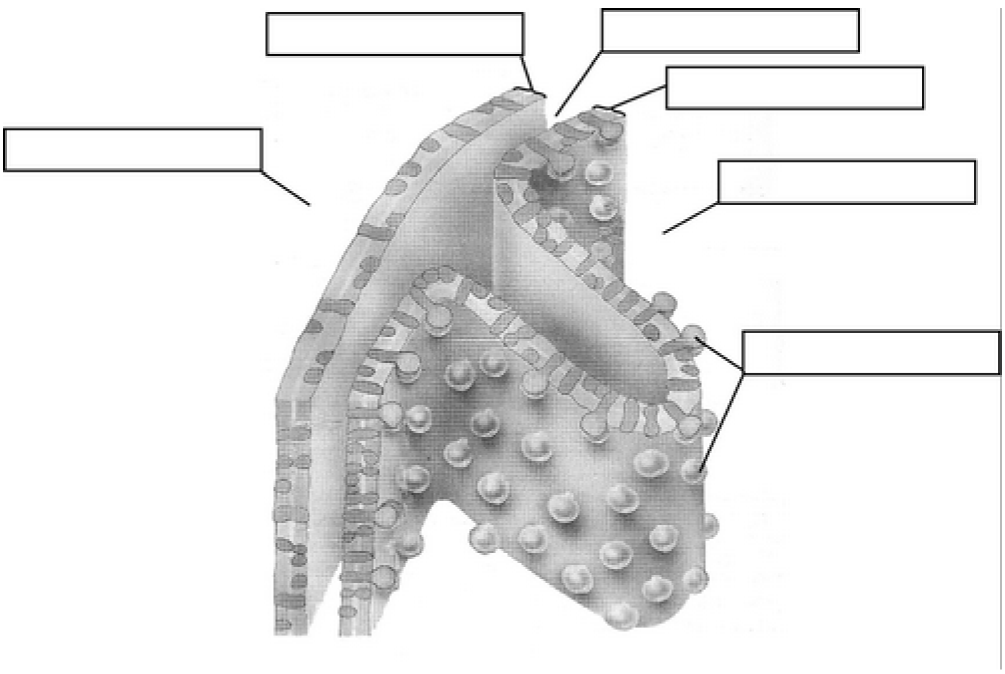
10. Proteins are often named after their function. What is the function of a "synthase"?

the formation of a substance
the transport of a substance
the splitting/decomposition of a substance
the disintegration of a substance
I don't know

11. Which is the function of the ATP synthase (ATPase)?

the transport of ATP molecules within the mitochondria
the transformation of an electro-chemical gradient in chemical energy
the transport of ATP molecules from the mitochondria into the cell lumen
the activation of the respiration chain by proton transport
I don't know

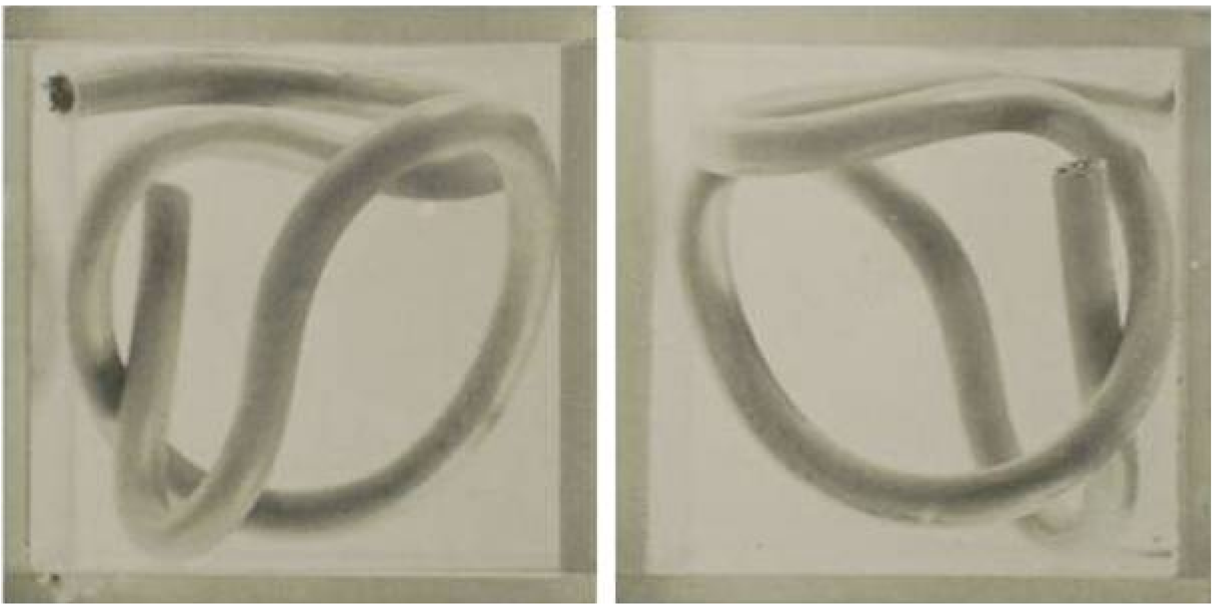
12. Please inscribe the following detail of a cell organelle!



To which organelle belongs this detail?

7.2.2 Test of visual spatial ability

In this investigation the spatial ability was measured with the tube figures test. In this test, students had to compare 21 different sets of pictures depicting a glass cube (without spatial cues as to the dimension of the cube) containing a winding flexible tube. In each set of pictures, the left picture showed the forefront of the cube, while the right picture portrayed the cube from a different side. Students had to decide from what angle the cube was shown on the right picture, i.e. from left/right/bottom/above/behind. The figure shows one sample set of pictures used in the test.



7.2.3 Questionnaire on learning styles

This questionnaire aims to highlight differences in learning style. Everybody has an individual way of learning. As there are no good or bad learning styles there are no right or wrong answers in this questionnaire.

In the following 44 questions two alternative answers will be provided respectively. Please circle or tick off (a) or (b) to indicate your answer to every question. Only **one answer** per question can be accepted. Even if both seem to apply to you, please decide for the one deemed more appropriate!

Please read the questions thoroughly and try to **answer spontaneously**.

1. I understand something better after I
   (a) try it out.
   (b) think it through.

2. I would rather be considered
   (a) realistic.
   (b) innovative.

3. When I think about what I did yesterday, I am most likely to get
   (a) a picture.
   (b) words.

4. I tend to
   (a) understand details of a subject but may be fuzzy about its overall structure.
   (b) understand the overall structure but may be fuzzy about details.

5. When I am learning something new, it helps me to
   (a) talk about it.
   (b) think about it.

6. If I were a teacher, I would rather teach a course
   (a) that deals with facts and real life situations.
   (b) that deals with ideas and theories.

7. I prefer to get new information in
   (a) pictures, diagrams, graphs, or maps.
   (b) written directions or verbal information.

8. Once I understand
   (a) all the parts, I understand the whole thing.
   (b) the whole thing, I see how the parts fit.

9. In a study group working on difficult material, I am more likely to
   (a) jump in and contribute ideas.
   (b) sit back and listen.

10. I find it easier
    (a) to learn facts.
    (b) to learn concepts.

11. In a book with lots of pictures and charts, I am likely to
    (a) look over the pictures and charts carefully.
    (b) focus on the written text.

12. When I solve mathematical problems
    (a) I usually work my way to the solutions one step at a time.
    (b) I often just see the solutions but then have to struggle to figure out the steps to get to them.

13. In classes I have taken
    (a) I have usually gotten to know many of the students.
    (b) I have rarely gotten to know many of the students.

14. In reading non-fiction, I prefer
    (a) something that teaches me new facts or tells me how to do something.
    (b) something that gives me new ideas to think about.

15. I like teachers
    (a) who work a lot with diagrams.
    (b) who spend a lot of time explaining.

16. When I am analyzing a story or a novel
    (a) I think of the incidents and try to put them together to figure out the themes.
    (b) I just know what the themes are when I finish reading and then I have to go back and find the incidents that demonstrate them.

17. When I start a homework problem, I am more likely to
    (a) start working on the solution immediately.
    (b) try to fully understand the problem first.

18. I prefer the idea of
    (a) certainty.
    (b) theory.

19. I remember best
    (a) what I see.
    (b) what I hear.

20. It is more important to me that an instructor
    (a) lays out the material in clear sequential steps.
    (b) provides me with the overall picture and relates the material to other subjects.

21. I prefer to study
    (a) in a study group.
    (b) alone.

22. I am more likely to be considered
    (a) careful about the details of my work.
    (b) creative about how to do my work.

23. When I get directions to a new place, I prefer
    (a) a map.
    (b) written instructions.

24. I learn
    (a) at a fairly regular pace. If I study hard, I will surely comprehend the content.
    (b) in fits and starts. I will be totally confused and then suddenly it all "clicks."

25. I would rather first
    (a) try things out.
    (b) think about how I am going to do it.

26. When I am reading for enjoyment, I like writers to
    (a) clearly say what they mean.
    (b) say things in creative, interesting ways.

27. When I see a diagram or sketch in class, I am most likely to remember
    (a) the picture.
    (b) what the instructor said about it.

28. When considering a body of information, I am more likely to
    (a) focus on details and miss the big picture.
    (b) try to understand the big picture before getting into the details.

29. I more easily remember
    (a) something I have done.
    (b) something I have thought about a lot.

30. When I have to perform a task, I prefer to
    (a) master one way of doing it.
    (b) come up with new ways of doing it.

31. When someone is showing me data, I prefer
    (a) charts or graphs.
    (b) text summarizing the results.

32. When writing a paper, I am more likely to
    (a) work on (think about or write) the beginning of the paper and progress forward.
    (b) work on (think about or write) different parts of the paper and then bring them into order.

33. When I have to work on a group project, I first want to
    (a) have "group brainstorming" with everyone to contribute ideas.
    (b) brainstorm individually and then come together as a group to compare ideas.

34. I consider it higher praise to call someone
    (a) sensible.
    (b) imaginative.
35. When I meet people at a party, I am more likely to remember
    (a) what they looked like.
    (b) what they said about themselves.

36. When I am learning a new subject, I prefer to
    (a) stay focused on that subject, learning as much about it as I can.
    (b) try to make connections between that subject and related subjects.

37. I am more likely to be considered
    (a) outgoing.
    (b) reserved.

38. I prefer courses that emphasize
    (a) concrete material (facts, data).
    (b) abstract material (concepts, theories).

39. For entertainment, I would rather
    (a) watch television.
    (b) read a book.

40. Some teachers start their lectures with an outline of what they will cover. Such outlines are
    (a) somewhat helpful to me.
    (b) very helpful to me.

41. The idea of doing homework in groups, with one grade for the entire group,
    (a) appeals to me.
    (b) does not appeal to me.

42. When I am doing long calculations,
    (a) I tend to repeat all my steps and check my work carefully.
    (b) I find checking my work tiresome and have to force myself to do it.

43. I tend to picture places I have been
    (a) easily and fairly accurately.
    (b) with difficulty and without much detail.

44. When solving problems in a group, I would be more likely to
    (a) think of the steps in the solution process.
    (b) think of possible consequences or applications of the solution in a wide range of areas.

Please check again if you really have answered all questions. Thank you!

7.3 Exemplary log files

<u>Encoding and decoding of the logfiles</u>

For security reasons the logfiles were encoded. A tool to encode and decode the logfiles was developed by the programmers of the CD-ROM. The following two screenshots show encoded and decoded logfile samples respectively.

Logfile examples

Sample logfile documenting the use of the content module plant cell

106	Zelle	Pflanzenzelle	Kern	11:51:32
106	Zelle	Pflanzenzelle	Plasmastränge/Vakuole	11:51:43
106	Zelle	Pflanzenzelle	Endoplasmatisches Reticulum	11:52:01
106	Zelle	Pflanzenzelle	Endoplasmatisches Reticulum	11:52:16
106	Zelle	Pflanzenzelle	Kern	11:53:16
106	Zelle	Pflanzenzelle	Kern	11:53:33
106	Zelle	Pflanzenzelle	Chloroplast	11:53:45
106	Zelle	Pflanzenzelle	Chloroplast	11:53:55
106	Zelle	Pflanzenzelle	Mitochondrium	11:54:25
106	Zelle	Pflanzenzelle	Mitochondrium	11:54:37
106	Zelle	Pflanzenzelle	Mitochondrium	11:54:50
106	Zelle	Pflanzenzelle	Mitochondrium	11:55:03
106	Zelle	Pflanzenzelle	Mitochondrium	11:55:29
106	Zelle	Pflanzenzelle	Dictyosom	11:55:57
106	Zelle	Pflanzenzelle	Menü - Notizen	11:56:17

Sample logfile showing the use of the cinema function

104	ATP	navi.dxr	Testbild	12:35:03
104	ATP	navi.dxr	Alle Filme	12:35:15
104	ATP	kino.dxr	atpase1	12:36:12
104	ATP	kino.dxr	inUp	12:37:07
104	ATP	kino.dxr	info	12:37:07
104	ATP	kino.dxr	inUp	12:37:17
104	ATP	kino.dxr	info	12:37:17
104	ATP	kino	Menü - 3d Labor	12:39:53
104	ATP	labor	Menü - Ende	12:40:03
104	ATP	Session Log Out		12:40:40

Sample logfile showing the navigation through the guided tour

102	ATP	ms010.dxr	bm_dnaUp	12:31:46
102	ATP	ms010c.dxr	Menü - Tour weiter	12:31:48
102	ATP	quiztour.dxr	Menü - Tour weiter	12:31:49
102	ATP	ms040.dxr	picogUp	12:31:57
102	ATP	ms040.dxr	mempotUp	12:32:16
102	ATP	ms040.dxr	Menü - Tour weiter	12:32:26
102	ATP	ms040.dxr	Menü - Tour weiter	12:32:55
102	ATP	ms020.dxr	Menü - Tour weiter	12:32:56
102	ATP	quiztour.dxr	Menü - Tour zurück	12:33:00
102	ATP	ms040.dxr	Menü - Tour zurück	12:33:02
102	ATP	ms010.dxr	Menü - Tour zurück	12:33:03
102	ATP	tour.dxr	but3Up	12:33:07
102	ATP	ms010.dxr	Menü - Tour Beenden	12:33:15
102	ATP	tour.dxr	but2Up	12:33:17
102	ATP	mf010.dxr	Menü - Tour weiter	12:33:27
102	ATP	quiztour.dxr	Menü - Tour weiter	12:33:30
102	ATP	mf020a01.dxr	Menü - Tour weiter	12:33:31
102	ATP	quiztour.dxr	Menü - Tour zurück	12:33:33
102	ATP	mf010.dxr	Menü - Tour weiter	12:33:37
102	ATP	quiztour.dxr	Menü - Tour weiter	12:33:39
102	ATP	mf020a02.dxr	Menü - Tour zurück	12:34:05
102	ATP	mf010.dxr	Menü - Tour zurück	12:34:07
102	ATP	tour.dxr	but4Up	12:34:10

Sample logfile showing the navigation on the sitemap

103	Zelle	mf0502d	Menü - Glossar	11:58:31
103	Zelle	glossar.dxr	Matrix	11:58:35
103	Zelle	glossar	Menü - Kompass	11:58:45
103	Zelle	navi.dxr	Mitochondrien Hauptmenü	11:58:50
103	Zelle	m010	Menü - Kompass	11:58:55
103	Zelle	navi.dxr	Stoffwechselwege	11:58:59
103	Zelle	mf020	Menü - Kompass	11:59:05
103	Zelle	navi.dxr	Zellatmung	11:59:07
103	Zelle	mf010.dxr	Frbispup	11:59:19
103	Zelle	mf010	Menü - Kompass	11:59:27
103	Zelle	navi.dxr	Funktioneller Aufbau	11:59:31
103	Zelle	ms010.dxr	bm_vr1Up	11:59:35
103	Zelle	ms010a.dxr	bm_crsUp	11:59:54
103	Zelle	ms010b	Menü - Kompass	12:00:23
103	Zelle	navi.dxr	EM-Bild	12:00:26
103	Zelle	ms020.dxr	ema1Up	12:00:34
103	Zelle	ms0205	Menü - Kompass	12:00:55
103	Zelle	navi.dxr	Tricarbonsäurezyklus	12:00:59
103	Zelle	mf060.dxr	but1Up	12:01:23
103	Zelle	mf060.dxr	bm_abbUp	12:02:31
103	Zelle	mf060.dxr	bm_abbUp	12:02:35
103	Zelle	mf060.dxr	bm_abbUp	12:02:41
103	Zelle	mf060.dxr	bm_abbUp	12:02:44
103	Zelle	mf060	Menü - Kompass	12:02:47
103	Zelle	Session Log Out		12:03:58
103	ATP	tour.dxr	but1Up	12:19:07
103	ATP	Tierzelle	Menü - Kompass	12:19:10

Sample logfile showing the use of notes

101	Zelle	m010	Menü - Notizen	11:56:20
101	Zelle	notiz.dxr	Schliessen	11:56:37
101	Zelle	m010.dxr	bfunkUp	11:56:37
101	Zelle	mf010.dxr	schere3	11:56:41
101	Zelle	mf010a	Menü - Notizen	11:57:00
101	Zelle	notiz.dxr	Schliessen	11:57:22
101	Zelle	mf010a.dxr	adp_up	11:57:29
101	Zelle	mf010a.dxr	p_Trioup	11:57:38
101	Zelle	MF010b	Menü - Notizen	11:57:58
101	Zelle	notiz.dxr	Schliessen	11:58:31
101	Zelle	MF010b.dxr	pyruvaup	11:58:34
101	Zelle	MF010c.dxr	bm_abbup	11:58:46
101	Zelle	MF010c	Menü - Notizen	11:58:57

Sample logfile showing the use of the glossary

116	Zelle	index	Menü - Glossar	11:49:26
116	Zelle	glossar	Menü - Kompass	11:49:39
116	Zelle	navi	Menü - Kompass	11:49:39
116	Zelle	navi.dxr	EM-Bild	11:49:52
116	Zelle	ms020	Menü - Kompass	11:49:58
116	Zelle	navi.dxr	Funktioneller Aufbau	11:50:02
116	Zelle	ms010.dxr	bm_vr1Up	11:50:15
116	Zelle	ms010a.dxr	bm_crsUp	11:50:20
116	Zelle	ms010b	Menü - Menü	11:50:51
116	Zelle	m010	Menü - Kompass	11:50:56
116	Zelle	navi.dxr	Allgemeine Grundlagen	11:51:07
116	Zelle	mf080	Menü - Kompass	11:51:20
116	Zelle	navi.dxr	Die Pflanzliche Zelle	11:51:25
116	Zelle	Planzenzelle	Video	11:51:29
116	Zelle	Pflanzenzelle	Film angehalten	11:51:32
116	Zelle	Pflanzenzelle	Film fortgesetzt	11:51:33
116	Zelle	Pflanzenzelle	Querschnitt	11:51:35
116	Zelle	Pflanzenzelle	Menü - Kompass	11:51:58
116	Zelle	navi.dxr	Die Tierische Zelle	11:52:37
116	Zelle	tp010.dxr	btz3dUp	11:52:58
116	Zelle	Tierzelle	Querschnitt	11:53:02
116	Zelle	Tierzelle	Menü - Glossar	11:53:43
116	Zelle	glossar	Menü - Kompass	11:54:06
116	Zelle	navi.dxr	Die Tierische Zelle	11:54:08
116	Zelle	Tierzelle	Video	11:54:11
116	Zelle	Tierzelle	Querschnitt	11:54:15
116	Zelle	Tierzelle	Menü - Glossar	11:54:30
116	Zelle	glossar	Menü - Kompass	11:54:59

Sample logfile showing the use of the quiz

103	ATP	navi.dxr	Quiz	12:30:06
103	ATP	quiz.dxr	Quiz-Videos	12:30:27
103	ATP	quiz.dxr	nxtvidUp	12:32:06
103	ATP	quiz.dxr	nxtvidUp	12:33:24
103	ATP	quiz.dxr	nxtvidUp	12:33:46
103	ATP	quiz.dxr	quituUp	12:34:28
103	ATP	quiz.dxr	Fragen zu Struktur und Vermehrung d	12:34:31
103	ATP	quiz.dxr	F(78),R(4),A(4)	12:34:45
103	ATP	quiz.dxr	F(92),R(2,4),A(1)	12:34:54
103	ATP	quiz.dxr	F(86),R(2,4),A(4)	12:35:11
103	ATP	quiz.dxr	F(86),R(2,4),A(1)	12:35:30
103	ATP	quiz.dxr	F(91),R(2),A(2)	12:35:44
103	ATP	quiz.dxr	F(88),R(2),A(1)	12:35:52
103	ATP	quiz.dxr	F(82),R(2),A(3)	12:36:13
103	ATP	quiz.dxr	F(84),R(3),A(4)	12:36:43
103	ATP	quiz.dxr	F(77),R(1,3),A(1)	12:36:59
103	ATP	quiz.dxr	F(77),R(1,3),A(2)	12:37:07
103	ATP	quiz	Menü - Glossar	12:37:17
103	ATP	glossar	Menü - Zurück	12:38:08
103	ATP	quiz	Menü - Kompass	12:38:12
103	ATP	navi.dxr	ATP-Synthase	12:38:15
103	ATP	Session Log Out		12:40:45

7.4 List of participating schools and universities

A huge thank you to the following schools and universitites that have participated in the investigation:

- Christophorusschule Braunschweig
- Lessinggymnasium Braunschweig
- Gymnasium Lehrte
- Eichsfeldgymnasium Duderstadt
- Gymnasium Lilienthal
- Gymnasium Munster
- Julianum Helmstedt
- Georg-Christoph-Lichtenberg-Gesamtschule Göttingen
- Otto-Hahn-Gymnasium Göttingen
- Lessing-Gymnasium Uelzen
- Theodor-Heuss-Schule Pinneberg
- Julius-Leber-Schule Hamburg
- Heinrich-von-Kleist-Schule Bochum
- Gymnasium an der Schweizer Allee Dortmund
- Friedrich-Bährens-Gymnasium Schwerte
- Kolping-Kolleg Rheinstetten
- Heinrich-Lanz-Schule II Mannheim
- Universität Göttingen – Didaktik der Biologie
- Technische Universität Braunschweig – Didaktik der Biologie
- Pädagogische Hochschule Karlsruhe – Didaktik der Biologie

Eidesstattliche Versicherung

Ich erkläre an Eides statt, dass ich diese Dissertation selbständig und ohne unzulässige Hilfe verfasst, andere als die angegebenen Quellen nicht benutzt und die den benutzten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Die Arbeit oder Teile davon wurden bisher weder im Inland noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde als Dissertation vorgelegt. Ferner erkläre ich, dass ich nicht bereits eine gleichartige Doktorprüfung an einer Hochschule endgültig nicht bestanden habe. Diese Arbeit hat keiner anderen Prüfungsbehörde vorgelegen.

Lebenslauf

Ausbildung/fachliche Qualifikation:

1989 - 1996	Studium der Biologie an der Eberhard-Karls-Universität Tübingen; Abschluss: Diplom (Sehr gut)
1992 - 1993	Integriertes Auslandsstudium an der Universidade de São Paulo in Brasilien (zwei Semester), gefördert durch ein DAAD-Stipendium
1996 - 1997	Ausbildung zum Fachzeitschriftenredakteur bei Klett WBS, München
2005- 2007	Referendariat, Lehrbefähigung für Gymnasien für die Fächer Biologie und Chemie, Seminar Esslingen

Berufliche Praxis:

seit Schuljahr 2007/08	Lehrkraft für Biologie und Chemie am Justinus-Kerner-Gymnasium in Heilbronn
Schuljahre 2005 - 2007	Referendar für Biologie und Chemie am Werner-Heisenberg-Gymnasium (1. Jahr) und Freihof-Gymnasium (2. Jahr), Göppingen
Schuljahr 2004 - 2005	Lehrkraft für Biologie am Salier-Gymnasium, Waiblingen
2002 - 2004	Wissenschaftlicher Mitarbeiter am Forschungszentrum L3S, Hannover und an der Technischen Universität Braunschweig, Lehrstuhl „Medieneinsatz in der Wissenschaft“: • Realisation eines Forschungsprojektes zum Einsatz neuer Medien in der Lehre im Bereich Zellbiologie/ Biochemie; Softwareevaluationen unter Beteiligung von ca. 700 Schülerinnen, Schülern und Studierenden • Lehre in den Studiengängen „Medienwissenschaften“ und „Biologiedidaktik“ der TU Braunschweig • Durchführung von Workshops • Mitarbeit in (inter)nationalen Kooperationsnetzwerken • Akquisition neuer Projekte
1998 - 2001	Redakteur und Projektmanager in der IWF Wissen und Medien GmbH, Göttingen in folgenden Projekten: • Kooperation mit der Charité in Berlin: Aufbau eines Multimedia-Zentrums für die Lehre in der Humanmedizin; Multimedia-Fortbildungen in der Charité • Aufbau eines Internet-Portals und einer Online-Datenbank für wissenschaftliche Medien in den Bereichen Biologie, Chemie, Psychologie, Medizin und Umweltschutz; Aufbereitung von Videos zur Verwendung in digitalen Systemen

- Internet-Auftritt zum Thema "Biologische Vielfalt"; Kooperation mit Intel; Präsentation des Produkts auf der Bildungsmesse 2001 in Hannover
- Konzeption und Realisation des Kapitels „Biologische Vielfalt“ für eine DVD-ROM zum Thema "Ökosystem Wald": multimediale Präsentation des Produkts auf der EXPO 2000 in Hannover und Publikation der DVD in Kooperation mit dem Buchverlag Parey Berlin

1997 - 1998	Journalistische Hospitanz und freie Mitarbeit in den Redaktionen "Umwelt" und "Gesundheit und Natur" des ZDF in Mainz: • Recherche • Erstellung von Kurzbeiträgen • Mitarbeit an einem Dreiteiler über die Serengeti; Erstellung von AVID-Sequenzen, Aufbau einer digitalen Datenbank
1997 - 1998	Praktikum und freie Mitarbeit beim FWU Institut für Film und Bild in Wissenschaft und Unterricht in München: • Film- und Videobearbeitung auf deutsch und englisch • Fachliche Begleitung eines Trickfilms • Erstellung und Überarbeitung von Begleitkarten zu diversen Videos und Filmen • Mitarbeit im Bereich neuer Medien
1997	Freie Mitarbeit beim amerikanisch-deutschen Wiley-VCH-Verlag in Weinheim: • Zeitschrift „Biologie in unserer Zeit“ • Zeitschrift „Fett / Lipid“ • Lektorat • Buchrezensionen • Marketing und Werbung
1997	Hospitanz und freie Mitarbeit in der Redaktion "Abenteuer Wissenschaft" des SWR in Mannheim: • Mitarbeit bei der Co - Produktion "Rette sich, wer kann!" von BBC (London), WGBH (Boston) und SWR • Recherchen zu biologischen und medizinischen Themen
1996	freie Mitarbeit bei der Zeitschrift "Abenteuer und Reisen", München
1994 - 1996	Praktikum und freie Mitarbeit bei der Brodbeck-Filmproduktion in München: Recherchen zu einem Vierteiler zum Thema "Bionik" des WDR und zu Kurzbeiträgen "Zukunft" für das ZDF